THE UNIVERSITY OF ALBERTA

FOLIAR MOISTURE CONTENT OF CENTRAL ALBERTA CONIFERS AND ITS IMPLICATIONS IN CROWN FIRE OCCURRENCE

by

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ABSTRACT

This study was undertaken to measure the seasonal and topographical variation of foliar moisture content and to relate these to crown fires in conifers of central Alberta. Sampling was carried out in lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), black spruce (*Picea mariana* (Mill.) B.S.P.) and the white spruce (*Picea glauca* var. *albertiana* (S.Brown) Sarg.) - Engelmann spruce (*Picea engelmannii* Parry) complex over a range of elevations in the foothills and Swan hills. Highly significant seasonal fluctuation was found on all locations sampled. Timing of seasonal minimum moisture was affected by elevation in lodgepole pine of the foothills and, likely, white-Engelmann spruce. However, in the Swan Hills, timing of the minimum in lodgepole pine was not affected by elevation. In black spruce, determination of the minimum was obscured by the high degree of variability over time. Over the entire sampling range, the minimum occurred in mid-May at low elevations and early-July at high elevations. Sampling was also carried out on four major aspects with lodgepole pine. Highly significant seasonal variation was found on all aspects. There were also highly significant differences between aspects (without replication), however, aspect had no affect on the pattern of seasonal variation.

Previous suggestions that timing of the minimum in

coniferous foliar moisture content is related to bud flushing was not supported by the results of this study. At high elevations the minimum occurred as much as 5 weeks after flushing. There appears to be some support, however, to discussion of possible relationships between soil temperature and foliar moisture content.

From analysis of fire records for the study area, it does appear that crown fire occurrence does have some relationship to the period of minimum foliar moisture content. However, by application of the sampling data through present crown fire theory, it is apparent that foliar moisture content variation may play a relatively small role in crown fire occurrence, second to surface fire intensity and stand structure, respectively. This would imply that foliar moisture content is important more as a correlative factor, working in combination with perhaps several other related factors.

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CHAPTER I

INTRODUCTION

Crown fires produce high fire intensities, measured at up to 22,500 kilowatts per metre of flame front (van Wagner 1968). Difficulty in controlling such fires is encountered due to intense radiant heating ahead of the fire and extreme convective development leading to long-distance spotting. Refinements in the ability to predict crown fires and their potential for extreme fire behavior such as high rate of spread and intensity, and spotting, reduce uncertainty in fire management planning.

A factor contributing to high fire intensity and the development of crown fires is low fuel moisture. In Alberta, the prominent occurrence of crown fires during early May has led to speculation that fluctuation of the moisture content of conifer foliage may be a related factor (Stashko and McQueen 1973).

CHAPTER II

PROBLEM STATEMENT

This study was undertaken to investigate the seasonal fluctuation of moisture content of the foliage of several common central Alberta coniferous tree species. The species chosen as representative of the area were lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), black spruce (*Picea mariana* (Mill.) B.S.P.) and the white spruce (*Picea glauca* var. *albertiana* (S.Brown) Sarg.) - Engelmann spruce (*Picea engelmannii* Parry) complex. Elevation and aspect were considered as a basis for sampling the extent and magnitude of foliar moisture content fluctuation. As a framework for the study of foliar moisture content, the following null hypotheses were tested:

A. For each selected species - effects of elevation

1. Foliar moisture content does not significantly differ between sampling periods at each elevational location sampled.
2. Foliar moisture content does not differ significantly between elevational locations sampled over the study period.
3. No patterns in seasonal moisture content fluctuation can be significantly attributed to elevation of the sampling locations.

B. For one of the selected species (lodgepole pine) - effects of aspect

4. Foliar moisture content does not significantly differ between sampling periods at the location sampled for each aspect.
5. Foliar moisture content does not significantly differ between aspect locations sampled over the study period.
6. There are no differences in the seasonal fluctuation pattern between aspects (interactive effect).

The observed seasonal fluctuation in foliar moisture content is considered in light of the factors relating to the physiology of the species studied as determined from the literature. Finally, an attempt is made to relate these fluctuations to crown fire danger and actual occurrence of crown fires in the past.

CHAPTER III

LITERATURE REVIEW

Foliar Flammability

The importance of varying moisture content of living vegetation has been discussed by Rothermel and Philpot (1973) and Countryman (1974) regarding the flammability of chaparral species (*Adenostomata* spp.) of Southern California. Both agreed that the condition of living vegetation is a strong determinant in fire behavior, the latter suggesting methods for monitering moisture content to refine management of natural and prescribed fire. Lindemuth and Davis (1975) found significant negative correlation between moisture content and fire intensity in oak chaparral (*Quercus turbinella* Greene) test fires in Utah. Leaf moisture content was also found to be a contributing factor in seasonal variation of flammability in fire resistant shrubs as studied by Montgomery and Cheo (1969). Philpot and Mutch (1971), however, concluded from a late spring and summer study in Washington and Oregon of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) and ponderosa pine (*Pinus ponderosa* Laws.) foliage, that the summer crown fire season may relate to extractive contents rather than moisture content.

The importance of foliar moisture content to flammability of coniferous vegetation has been investigated

in two laboratory experiments. Van Wagner (1963) described the effect of moisture content on flammability of Christmas trees. These were dried to foliar moisture contents ranging from near 0% to 70% (dry weight moisture percent) in Scots pine (Pinus sylvestris L.), balsam fir (Abies balsamea (L.) Mill) and white spruce (Picea glauca (Moench) Voss.) and a strong relationship to flammability was found. Quintilio (1977) has also found that flammability of lodgepole pine saplings (Pinus contorta var. latifolia Engelm.) correlated strongly to induced foliar moisture contents from 70% to 120% (reflecting more natural moisture content values).

In coniferous fuel types, the discovery of a period of minimum foliar moisture content during early spring has been speculatively associated with heightened crown fire occurrence and behavior during the same period (Stashko and McQueen 1973). In an assessment of fire behavior in sand pine (Pinus clausa (Chapm.) Vasey), Hough (1973) hypothesized that a correlation exists between the seasonal timing of extreme fire behavior and a combination of low foliar moisture, high ether extractive and reduced phosphorus contents in the needles.

Attempts to model potential foliar moisture contribution to fire danger have been made in Ontario, based on normal foliar moisture content behavior (van Wagner 1974(b)), and in Alberta, on weather parameters (Stashko and McQueen 1973). Van Wagner (1977) has developed a theoretical

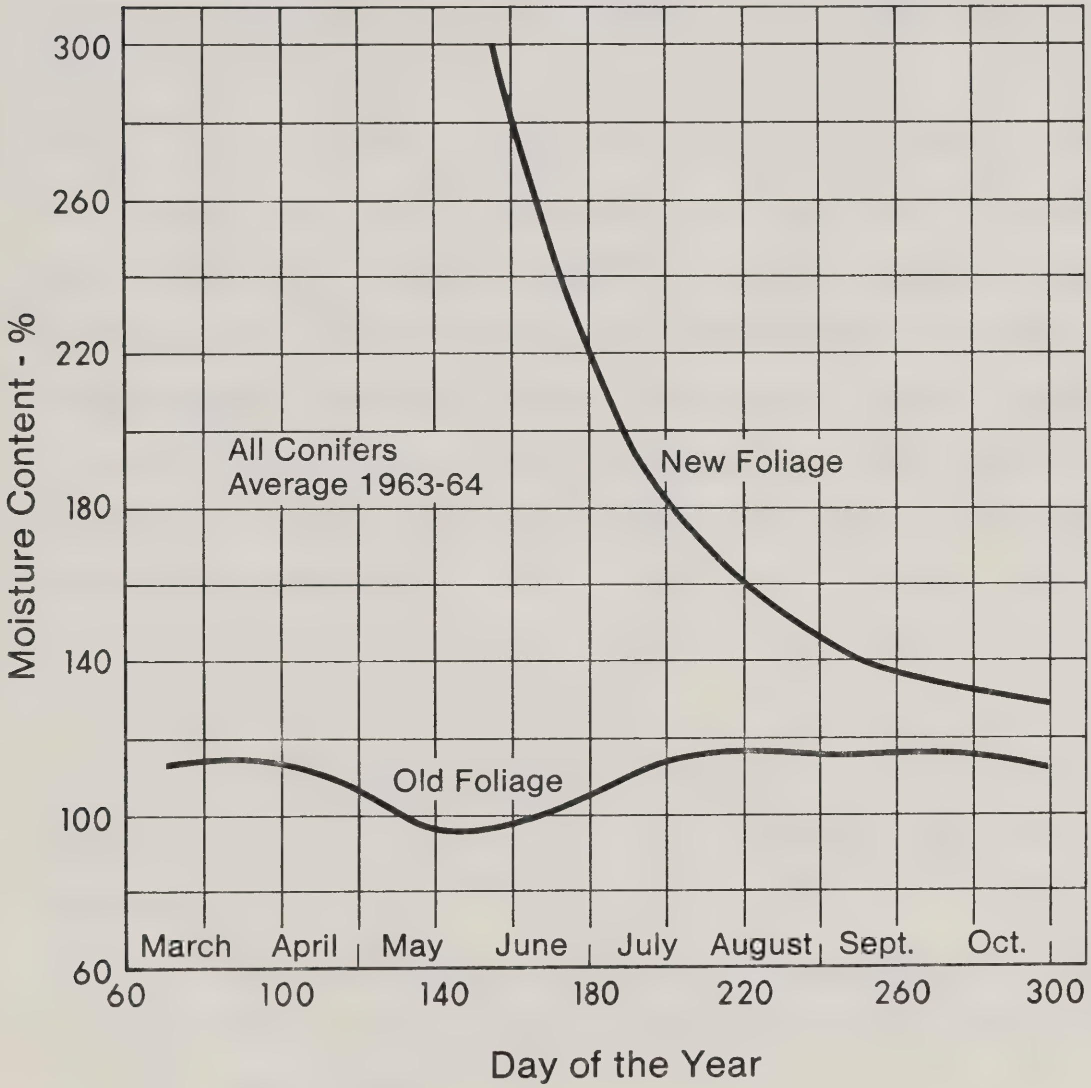
model to predict crown fire behavior based on foliar moisture content, crown bulk density, crown base height and surface fire intensity. Applied to the results of eight experimental fires, the theory outlines a framework through which foliar moisture content in combination with stand structure and wind may affect flammability. However, in an operational assessment of fire behavior in large fires in Alberta, it was felt that foliar moisture content may play less of a role than previously expected (Kiil, *et al.* 1977).

Foliar Moisture Content Sampling

A number of investigations has been undertaken to study the phenomenon of spring coniferous foliar moisture content minima. In the steppe region of Russia, Kurbatskii (1972) found spring foliar minima to occur consistently amoung 35 year old Scots pine, Norway spruce (*Picea abies* (L.) Karst.), and Siberian larch (*Larix sibirica* Lebed.). In North America, Jameson (1966) has also found a spring foliar moisture minimum with pinyon pine (*Pinus edulis* Engelm.) and juniper (*Juniperis scopulorum* Sarg.). Johnson (1966) has described similar results in red pine (*Pinus resinosa* Ait.).

In eastern Canada, van Wagner (1967) found that in the five conifers sampled, white pine (*Pinus strobus* L.), jack pine (*Pinus banksiana* Lamb.), red pine, white spruce and balsam fir, all exhibited a characteristic spring foliar moisture minimum (Figure 1). Foliage sampling in Alberta by

Figure 1. Average seasonal variation of the foliar moisture content of five eastern Canadian conifers (white pine, jack pine, red pine, white spruce and balsam fir - from: van Wagner 1967).



Chrosciewicz (1976) has yielded similar results for jack pine, white spruce, black spruce (Picea mariana (Mill.) B.S.P.), and balsam fir.

Association of this spring minimum with bud flushing appears to be generally accepted among most fire researchers. Russell and Turner (1976), for example, in sampling lodgepole pine, subalpine fir (Abies lasiocarpa (Hook.) Nutt.) and Engelmann spruce (Picea engelmannii Parry), found "a zone of minimum foliar moisture content that would be expected to progress upward as the state of flush advances". Pharis (1967), however, found in a physiological investigation that Douglas-fir and grand fir (Abies grandis (Dougl.) Lindl.) seedlings, despite induction of early flushing as part of a seedling stress experiment, developed moisture content minima at the same time as untreated seedlings.

Physiological Investigations

The water component of living parts of plants, as the variable under study, is involved in several important life functions:[1]

1. as the major common element of protoplasmic media containing solutes, colloidal proteins and lipids, and plant organelles,

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[1] Adapted from: Salisbury and Ross 1969 and Crafts 1968(a&b)

2. as the hydraulic medium providing turgidity to cells,

3. as a mechanism for heat stabilization and transfer through evaporation and transport, respectively,

4. as a medium for nutrient transport to above-ground plant parts for maintenance, growth and chemosynthesis,

5. as a medium for translocation of chemosynthetic material from production to storage and utilization sites.

A great deal of study has been directed at determining the physiological mechanisms for, and effects of water uptake, retention, movement and release in plants. As described by Cowan and Milthorpe (1968), an important principle in the water balance of trees is that of water potential, the chemical potential of water to do work (generally expressed in terms of negative pressure). Movement of water through plant tissue depends on the existence of an energy potential resulting from a water potential gradient across the tissue. The water flow equation, derived from Ohm's law is expressed as (Van den Honert 1948):

$$f = \frac{\Delta\psi}{Rs} = \frac{\Delta\psi}{Rr} = \frac{\Delta\psi}{Rx} = \frac{\Delta\psi}{Rl} = \frac{\Delta e}{Rv}$$

where:

f = the water flow under steady state,

$\Delta\psi$ = the water potential gradient across a flow section

R = the resistance to water flow (s=stem, x=xylem, r=root, l=leaf, v=vapor)

Δe = the vapor pressure gradient from inside to outside the plant (i.e. leaf)

In the steady state condition where the water flow into the plant equals the loss of water to the air and photosynthesis, the above equalities will have to hold true. By this principle, movement of water is determined by its availability and the resistance it encounters in passing through the applicable tissue. For the purposes of this study, it is important to note that flow of water through foliage is affected by the resistance created by soil moisture tension and passage through the intervening roots and xylem. Flow is also affected by the driving force, namely the potential of the air to overcome the leaf resistance which is created through stomatal control and the internal resistance of the leaf cells.

The relationship of leaf water potential to seasonal leaf moisture content behavior is not yet clearly understood. However, studies are presently underway to define possible elements of the relationship (Mayo 1976 and Richards 1977). Note of spring decline in water potential (increase in indicated moisture stress) as opposed to the expected winter extreme was first reported with Engelmann spruce by Walter in 1931.

Observations since have led to varying speculation on the possible causes of minimum seasonal coniferous foliar water potential. Sakai (1969), reported high spring water stress (low water potential) of mountain conifers (including white spruce), which he assumed to be the result of soil moisture tension resulting from frozen conditions. An examination of seasonal water stress in high-elevation krummholtz Engelmann spruce in Utah led Hansen and Klikoff (1972) to explain the extreme winter water potential values found in exposed foliage as a result of frozen soil. With timberline Engelmann spruce and subalpine fir, Lindsay (1971) also found low water potential during the winter. He speculated this was a result of strong winds in combination with frozen soil. Richards (1977) argued that soil temperatures somewhat above freezing (up to 5° C) may also be limiting to root activity, resulting in a continuation and perhaps accretion of moisture stress following soil thaw.

Pharis (1967), however, found with Douglas-fir, grand fir, sugar pine (*Pinus lambertiana* Dougl.) and incense cedar (*Libocedrus decurrens* Torr.) seedlings, that spring moisture deficits, which occurred despite high soil moisture contents, accompanied changes in osmotic pressure of the cell solutions. The early season difference in leaf water potential behavior concurs with findings of Mayo (1976) in jack pine and black spruce and Richards (1977) in high elevation lodgepole pine and Engelmann spruce. This leads to the speculation that apparent *decline* in relative moisture content may in fact be a *relative increase* in leaf solute content, likely photosynthates, or both effects combined through proportionate moisture displacement as proposed by Kozlowski and Clausen (1965).

Photosynthate accumulation in coniferous foliage during spring has been documented by Little (1973) with balsam fir, being a result of photosynthesis exceeding assimilation and respiration. The maximum level of accumulation occurred just before bud-burst. Gary (1971), investigating seasonal foliar moisture content of 30 year old Engelmann spruce found little change in absolute moisture content over the minimum period. He did, however, find a more significant change in the dry weights of the needles themselves over the period, giving speculation that the dry matter was translocated from other portions of the trees. Increases in dry needle weight concurrent with foliar moisture minima has also been

documented by van Wagner (1974(b)).

With regard to short-term moisture balances, Mayo (1976) has found some important differences in environmental water relation responses in Alberta conifers. In studying leaf resistance (which is generally a plant's response to water stress through increase in stomatal resistance), he states that lodgepole pine is able to maintain more stable water potentials while undergoing environmental stress than black spruce. This is effected by means of more responsive stomatal control in pine. Cline (1974) reported that western white pine (Pinus monticola Dougl.) also exhibited more responsive stomatal control than broadleaf species on the same sites.

Summary

The literature related to this study demonstrates the interest of several disciplines in foliar moisture behavior. These investigations have resulted in valuable observations and have also led to interesting questions on the subject.

The existence of minima in foliar moisture content during the spring period has been documented for many coniferous species in the northern hemisphere. Whether or not the variation in moisture content is in fact a change in the absolute water content or a result of the means by which it is measured has yet to be established. It may more accurately be a reflection of relative changes in weights of

other foliar components.

The relationship of physiological conditions which are associated with minimum foliar moisture content are not yet satisfactorily defined either. However, it does appear that cold soil temperatures are restricting to root activity, possibly affecting nutrient translocation from the leaves.

Finally, the significance of live foliar moisture content on flammability has not yet been defined. Experiments with artifically dried conifer saplings may not reflect the flammability of trees undergoing natural physiological changes.

CHAPTER IV

METHODS

STUDY AREA

The study area was selected on the basis of documented spring crown fire occurrence. It comprised the Swan Hills (Alberta high interior plains) and adjacent foothills (western Cordillera) regions of Alberta, in the Rocky-Clearwater, Edson, Whitecourt, Grande Prairie and southern Slave Lake Forests (Figure 2). The resulting area includes parts of three forest regions as defined by Rowe (1972): the East Slope Rockies (SA.1), the Upper Foothills (19c) and the Lower Foothills (19a) regions. A description of edaphic and climatic conditions of the study area appears in Table 1.

Three predominant species were subjects of this survey: lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), black spruce (*Picea mariana* (Mill.) B.S.P.) and the white spruce (*Picea glauca* var. *albertiana* (S.Brown) Sarg.) - Engelmann spruce (*Picea engelmannii* Parry) complex as described by Rowe (1972) (herein referred to collectively as white-Engelmann spruce).

Following initial field studies, it was decided to divide the survey into two areas. The first area represents the Swan Hills, over which the predominant lodgepole pine/black spruce type was sampled. The second represents the foothills region from Edson to the Alberta Forest

Figure 2. Map of Alberta showing the area of spring crown fire occurrence represented by this study.

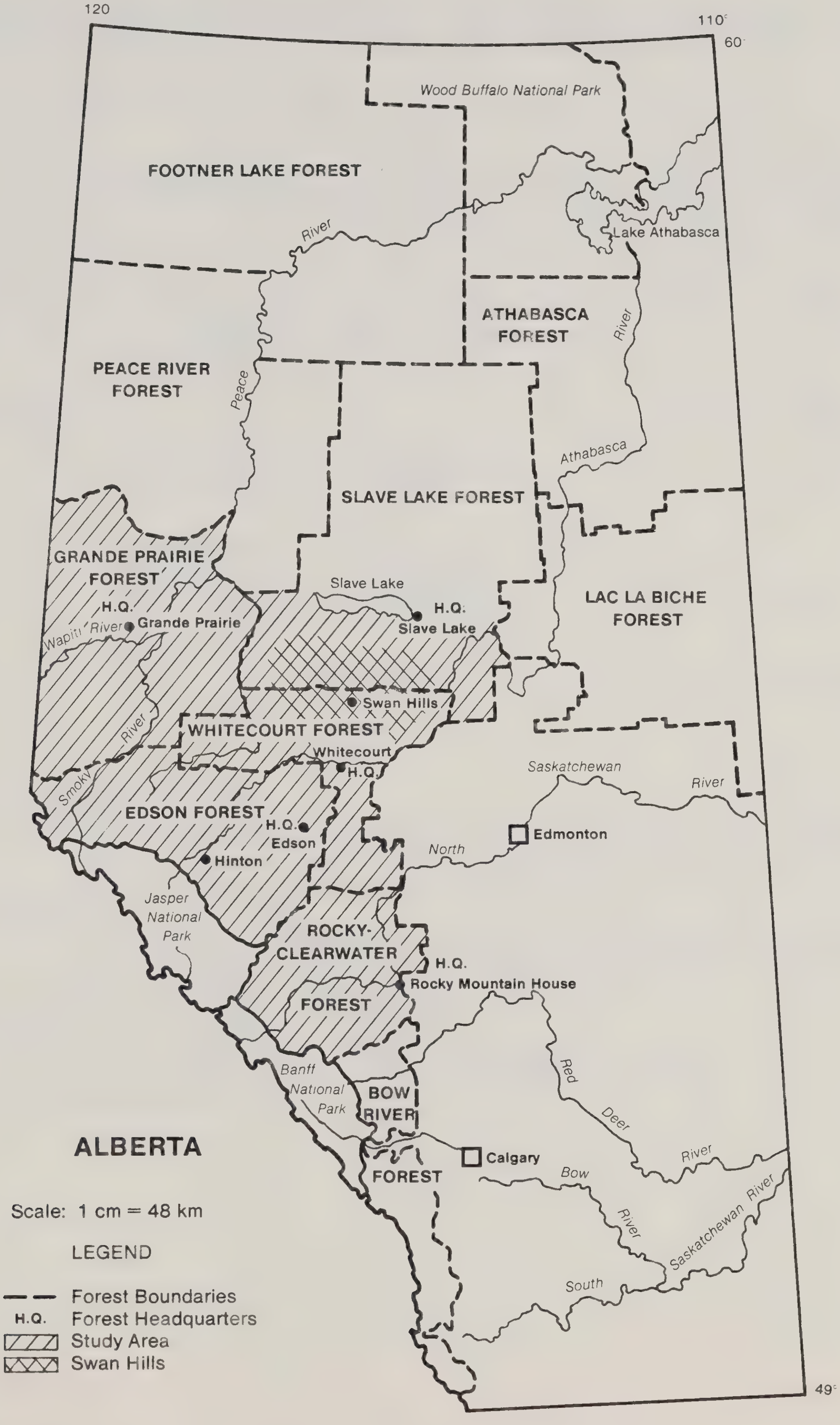


Table 1. Edaphic and climatic description of the study area (Adapted from: Clayton, *et al*. 1977 and Patching 1977)

Transect	Soil: Classification (Can.Surv.:FAO/UNESCO)	Soil: Climate[1] Moisture[2] (Can.Surv.)	Climate: Temp. (°C ann. mean)	Climate: Precip. (cm/ year)	Climate: Sunshine (hours/ year)
Swan Hills	Gray wooded luvisol (C2/34,35:La2-2b)	Cryoboreal Humid, Aquic (3.1e/b)	10-16	45-60	2000-2200
Foothills			7-10	50-60	1900-2200
<1370m	Gray wooded luvisol (C2/61:La6-2n)	Cryoboreal Humid (3.1e)			
>1370m	Orthic gray luvisol to rockland (R/23:I-Be-1c)	Subarctic Humid to Subhumid (2-3.1ef)Mx[3]			

[1] Cryoboreal; cold
- Mean ann. soil temp.: 2 to 8°C, summer: 8 to <15°C
- Grow. season (@≥5°): 120 to 180 days (beg. early May)
- Grow. season: 555 to 1110 degree days

Subarctic; very cold
- Mean ann. soil temp.: -7 to <2°C, summer: 5 to <8°C
- Grow. season (@≥5°): <120 days (beg. early June)
- Grow. season: <555 degree days

[2] Humid; slight moisture deficit
Subhumid; significant moisture deficit
Aquic; saturation for moderately long periods

[3] Mx; mountain effects

Service lookout at Grave Flats (Redcap Mountain), over which lodgepole pine and white-Engelmann spruce predominate.

SAMPLING TECHNIQUE STUDIES

Initial studies were carried out during the 1976 field season to develop sampling techniques. Experiments were conducted to determine amounts of sample material (foliage) required and possible effects of various means of transportation to weighing stations and the laboratory. It was found that a 10 gram fresh-weight sample of needles maintained more than 99% of its moisture in a covered and cooled container over 4 hours. Drying at 100° C for 24 hours removed 99% of the moisture of lodgepole pine and 99.8% of white spruce needles.

In August of 1976, four entire crowns were destructively sampled in order to estimate the source of variation of moisture content of the 1975 needles within them. It was determined that considerable variation existed between individual branches. Although no variation was detected between crown-face position (north, east, south or west facing branches, respectively), it was found that foliar moisture content did significantly decrease with increasing relative branch height within the crown, at a rate of 0.625% per metre (Appendix I). To minimize possible effects from relative branch position which could occur during the critical sampling periods, samples were collected

from lower-middle south-facing branches.

SAMPLE LOCATION AND TREE SELECTION

Initial guidelines for sampling location establishment were directed toward obtaining results representative of the sampled areas. Site and stand conditions described by Wambolt (1973) as most important to the moisture balance of conifers were soil charateristics and stand density. Therefore efforts were made to select locations of comparable stand density and with soil textures and drainage representative of the sample area.

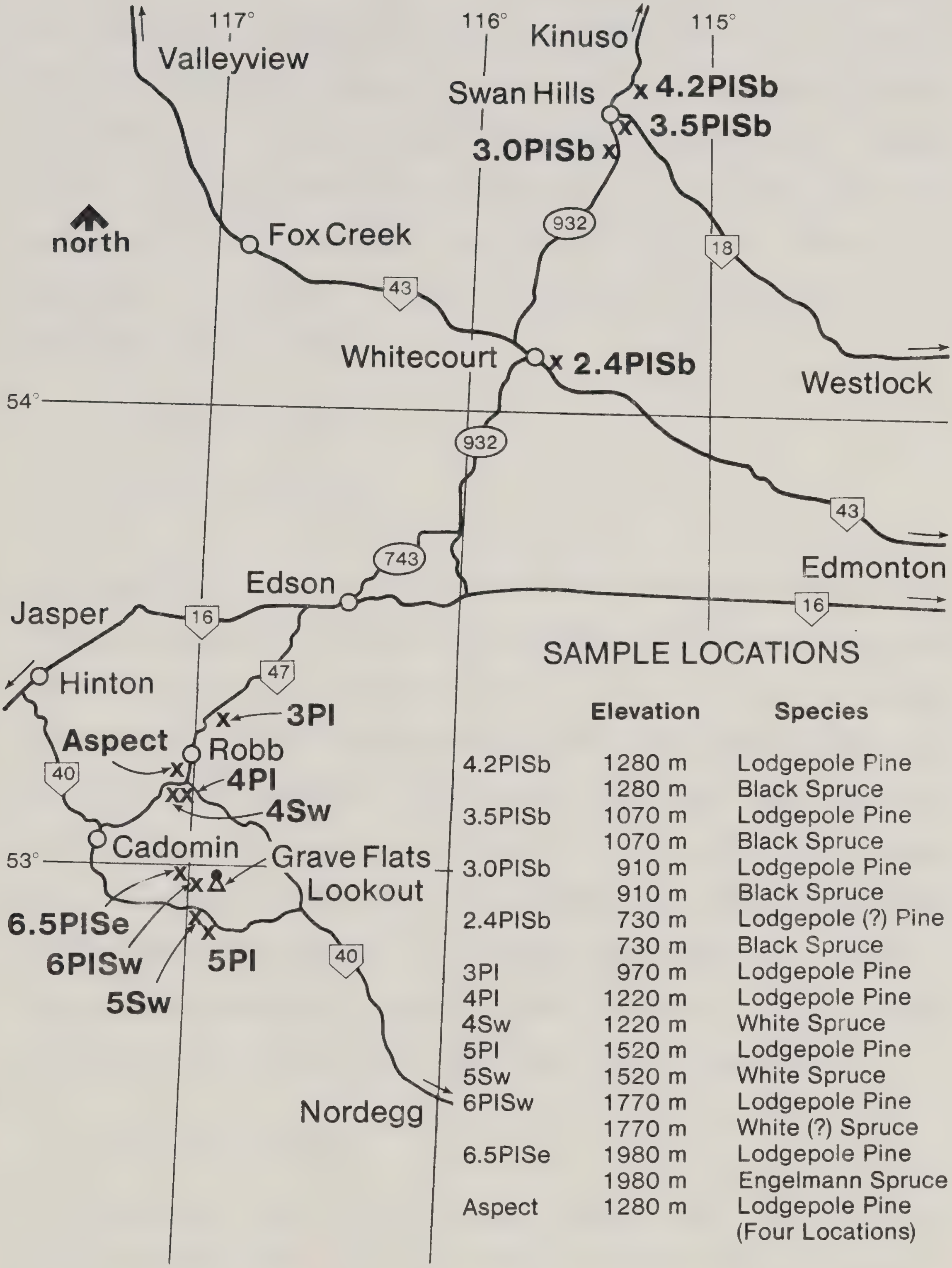
Two additional major factors which entered into selecting sampling locations were accessibility and stand structure (height and density). Accessibility was important for over-winter and early-spring foliage collection. Stand height was limiting because of the reach of the equipment available for sample extraction. Using pruning poles with a reach of 10 to 12 metres, enough crown material had to be available to allow 20 to 25 samples. Based on this constraint, late immature stands were necessarily selected. Tentative age limits of 60 to 75 years were established to reduce possible effects introduced by stand age. A medium stand density was chosen (40 to 50% crown closure) to minimize effects of this variable.

The availability of suitable sites over the gradient of elevations of the two areas allowed the selection of four

sampling locations of white-Engelmann spruce and five of lodgepole pine in the foothills (the two highest elevation locations are of pine and spruce combined), and four sampling locations of lodgepole pine/black spruce in the Swan Hills. The sampling locations and elevations are shown in Figure 3. Only one suitable and accessible site was found on which to establish plots to measure the effect of aspect on foliar moisture content. Up to eight sample trees were selected at each sampling location, generally within practical sampling distances of each other and as close as possible to the accepted age limits.

Once sampling locations had been selected and foliage from the sample trees collected, the variance of samples collected in August from the destructively sampled crowns was used to decide whether the variance measured was a result of inter-tree variation in foliar moisture content, or an effect of natural variation found within each crown. By random selection of eight samples from within each of the crowns sampled during August, (from lower-middle south-facing branches) the variances were compared to the variances of the foliage of the sample trees. No significant difference was found (Appendix 1), thereby allowing the assumption that samples collected randomly from preselected crowns would represent independent observations of the foliar moisture content of branches of crowns locally fitting the preselection criteria.

Figure 3. Map of sample locations used in studying coniferous foliar moisture content variation (1 cm = 7.1 km).



SAMPLE LOCATIONS

	Elevation	Species
4.2PISb	1280 m	Lodgepole Pine
	1280 m	Black Spruce
3.5PISb	1070 m	Lodgepole Pine
	1070 m	Black Spruce
3.0PISb	910 m	Lodgepole Pine
	910 m	Black Spruce
2.4PISb	730 m	Lodgepole (?) Pine
	730 m	Black Spruce
3PI	970 m	Lodgepole Pine
4PI	1220 m	Lodgepole Pine
4Sw	1220 m	White Spruce
5PI	1520 m	Lodgepole Pine
5Sw	1520 m	White Spruce
6PISw	1770 m	Lodgepole Pine
	1770 m	White (?) Spruce
6.5PISe	1980 m	Lodgepole Pine
	1980 m	Engelmann Spruce
Aspect	1280 m	Lodgepole Pine (Four Locations)

As shown in Appendix 1, based on the variance of the first set of samples, a sample size of six was chosen in order to statistically resolve (at $P<5\%$) the 7 to 10% foliar moisture content change per week observed in other studies. Once the final sampling locations were established, sample trees for the locations were designated as those whose ages most closely approached the ideal age (65 years). The sampling locations, and respective sample trees are described in Appendix 2.

SAMPLING METHODS

Foliage collection

Sample foliage was collected from branches severed with a pruning shear from the lower-middle south-facing portions of crowns of the selected trees. In this study only needles originating in 1976 were sampled. For lodgepole pine the needles were removed by plucking them from the fascicles, whereas for both species of spruce it was necessary to shear the foliage with scissors. All samples were then transported within capped containers in a cooler and weighed within 3 hours of sampling. Samples were weighed to the nearest centigram (±.02 gram) on a Sartorius top loading scale.

Sampling interval

Sampling over the winter months was attempted at monthly intervals so that winter moisture levels could be

determined. Initiation of the spring decline then was detected and sampling increased to about once a week during the period of minimum foliar moisture content. For the sake of analysis, attempts were made to maintain orthogonality, ensuring that samples would be obtained for each location for each sampling period. However, sampling was not carried out if there was evidence of free surface moisture (from condensation, fog, rain or snow) present on the needles. Sampling began on October 9, 1976 and was completed October 23, 1977.

Sampling results

Due to weather conditions during the study period, results were not obtained for each of the elevational sampling locations for each period. Winter sampling was hampered by the presence of snow on the foliage during several attempts. March and April were abnormally warm and dry, allowing numerous sampling opportunities, but by May the weather had become extremely wet in the study area, and on two occasions the sampling process was interrupted by rain. The summer period was also wet, but no interference was encountered again until August. As the orthogonality of sampling had been disrupted, preference was directed to sampling trees on those locations apparently undergoing the spring minimum phenomenon in order to ascertain extreme minimum values.

CONCOMITANT DATA COLLECTION

Soil temperatures were taken during April, May and June at two depths (15 cm and 30 cm), representative of rooting depths of the conifer species sampled. Temperatures were taken during foliar moisture sampling procedures with a single stemmed dial-thermometer (18") inserted for 10 minutes into polyethylene tubes sealed and capped in the soil.

Air temperatures at the time of sampling were recorded, as were maximum and minimum temperatures for the period since previous sampling. At the mid-elevation sampling location of the upper foothills (1770 m), a meteorograph (measuring temperature, humidity and barometric pressure) was installed in place of the max-min thermometer.

In order to measure possible drought conditions, precipitation was also recorded with simple rain guages at each location. Temperature and precipitation data were collected at each sampling date, representing the period between samples, from April to October, 1977.

Recording of phenological development was also maintained over the spring period. Approximate dates of flushing were estimated as the likely date when 50 percent of the bud scales would have separated from their bases, based on observations of the branches sampled for foliar moisture content.

White spruce was expected to flush early to mid-May, with reproductive bud growth (dependent on warm late-spring weather) occurring in early August (Fraser 1962). Black spruce was expected to flush mid- to late-May (about 2 weeks later than white spruce), with reproductive bud growth (dependent on a warm early-spring) also appearing in early August (Fraser 1966). In the absence of published literature on the development of lodgepole pine buds, a description of the development of jack pine compiled by Curtis and Popham (1972) served as a reference. The authors describe observations of staminate cone production in late-April and early-May followed by needle flush in late-May.

DATA PRESENTATION

The results of this study require a substantial degree of graphical representation to adequately describe them in a context meaningful both to the study and previous work. Supplemental to the conventional line graph illustrations (similar to Figure 1) there is a number of three-dimensional representations, where the dependent variable is plotted in the form of isoquants (for the cases of foliar moisture content, ignitibility model values and soil temperature results) on a matrix of the two independent variables - time of year (determinant axis) and elevation (ordinant axis). The isoquant lines have been determined with a combination of Laplacian and Spline interpolation and extrapolation as

applied by the SCCONT subroutine used by U. of A. M.T.S. graphics. The figures themselves were constructed using digital plotting routines and were drawn by the Calcomp plotter of the system.

STATISTICAL ANALYSIS

The data for the species of each area and for the aspect locations were analyzed in a two-way analysis of variance. This entailed using the sample date (or period) and sampling location (elevational or aspect) as main effects, with sample values as the residual source of variance. With an anticipated 20 sampling periods throughout the sampling interval (October, 1976 to October, 1977), the analysis would be structured as 20 periods by 5 elevations for foothills lodgepole pine and 20 periods by 4 elevations or aspects for the other four sampling series.

Testing of Hypotheses 1 and 4 was done under two-way analyses of variance through evaluation of the main effect of sampling period on the data for the species of each transect and the aspect locations. Additionally it was important to test the data from each sampling location by one-way analysis of variance to ascertain the absolute extent of significant seasonal moisture content fluctuations. Hypotheses 2 and 5 were tested through evaluation of the main effect of sampling location on the data. Significance of the interaction term (period x

elevation or aspect) was interpreted as the independence of *fluctuation* between sampling locations, namely whether fluctuations at the locations of an area were statistically different from each other (as the determining effect for Hypothesis 6, and in interpretation of Hypotheses 2 and 3).

Two-way analysis of non-orthogonal results was carried out using a method described by Henderson and McAllister (1978). The two-way analyses were applied to the maximum number of periods to allow determination of main and interaction effects. This conforms to the third method which they have outlined, whereby at least one row and one column of the analysis matrix must be complete to calculate interaction effects.

In addition to analyses of variance to determine the level of significance of differences between periods and sampling locations, multiple comparisons were also carried out at the 5% probability level. Tukey's multiple comparison test was chosen for the purpose.

As a means of relating fluctuations of foliar moisture content to elevation, the following step-wise polynomial F - test was performed for the species of each transect for each period (Nie, *et al*. 1975):

F - test for null hypothesis (no difference between means) for the equation:

$$Y = A + B^1X^1 + B^2X^2 + B^3X^3 + \ldots + B^KX^K$$

$$F = \frac{(R^2 \text{ with Kth order term}) - (R^2 \text{ without Kth order term})}{(1 - R^2 \text{ with Kth order term})/(N-K-1)}$$

with 1 and (N-K-1) degrees of freedom

The <u>deviation from linearity</u> term, also described, can be used to determine whether the polynomial adequately describes or predicts the group means. A significant result implies that the values are not adequately described by the polynomial relationship. To test for the trend described by Russell and Turner, 1976 (Hypothesis 3), a series of polynomial tests over the minimum period was performed. The existence of such a trend would be revealed as a period of significant positive linear relationships (low foliar moisture content at low elevations) during the early minimum period followed by a significant negative linear relationship period.

Finally, the possibility for correlation analysis to model the spring foliar moisture content behavior was also considered. From the literature, soil temperature appeared to be the most likely variable (probably best described as quadratically related to foliar moisture content during the spring period), but if strong evidence could be given for relating other of the concommitant variables, they could also be included in a multiple correlation analysis.

The statistical analyses for this study were computed using the Statistical Package for the Social Sciences, Version 6, at the University of Alberta.

CHAPTER V

RESULTS and DISCUSSION

EFFECTS OF ELEVATION

Seasonal minimum occurrence

As can be seen in Figures 4 through 7, results obtained for elevational sampling locations generally follow the results presented by van Wagner (1967). The seasonal fluctuation in moisture contents were tested by individual one-way analyses of variance, which showed highly significant ($P<1\%$) variation over time for all sampling locations.

Foothills lodgepole pine

The moisture content of lodgepole pine foliage of foothills sampling locations (Figure 4) appeared to have been reasonably stable through the winter. Moisture content began to decrease in early to late April. Initiation of spring decline appeared to occur up to 2 weeks later at high elevations than at low elevations. Prominent spring foliar moisture content minima occurred in late-May at low elevations (910 and 1040 m) and in mid-July at high elevations (1770 and 1980 m) - a difference of about 6 weeks. The minimum at the 1520 m location, although not as pronounced, was estimated to have occurred in late-June. Recovery from the minima was somewhat slower than expected

Figure 4. Foliar moisture content (dry weight moisture percent) of lodgepole pine at foothills sampling locations (each plotted value is the mean of six observations).

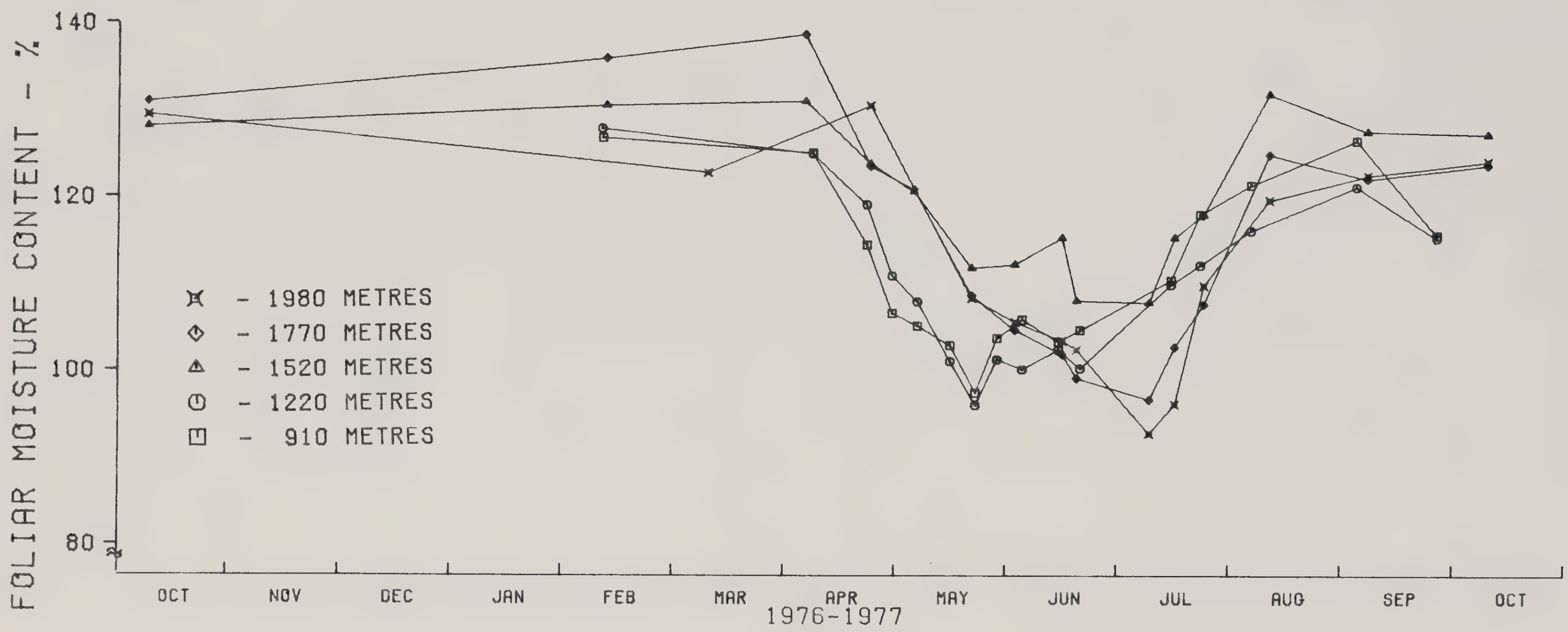


Figure 5. Foliar moisture content (dry weight moisture percent) of white-Engelmann spruce at foothills sampling locations (each plotted value is the mean of six observations).

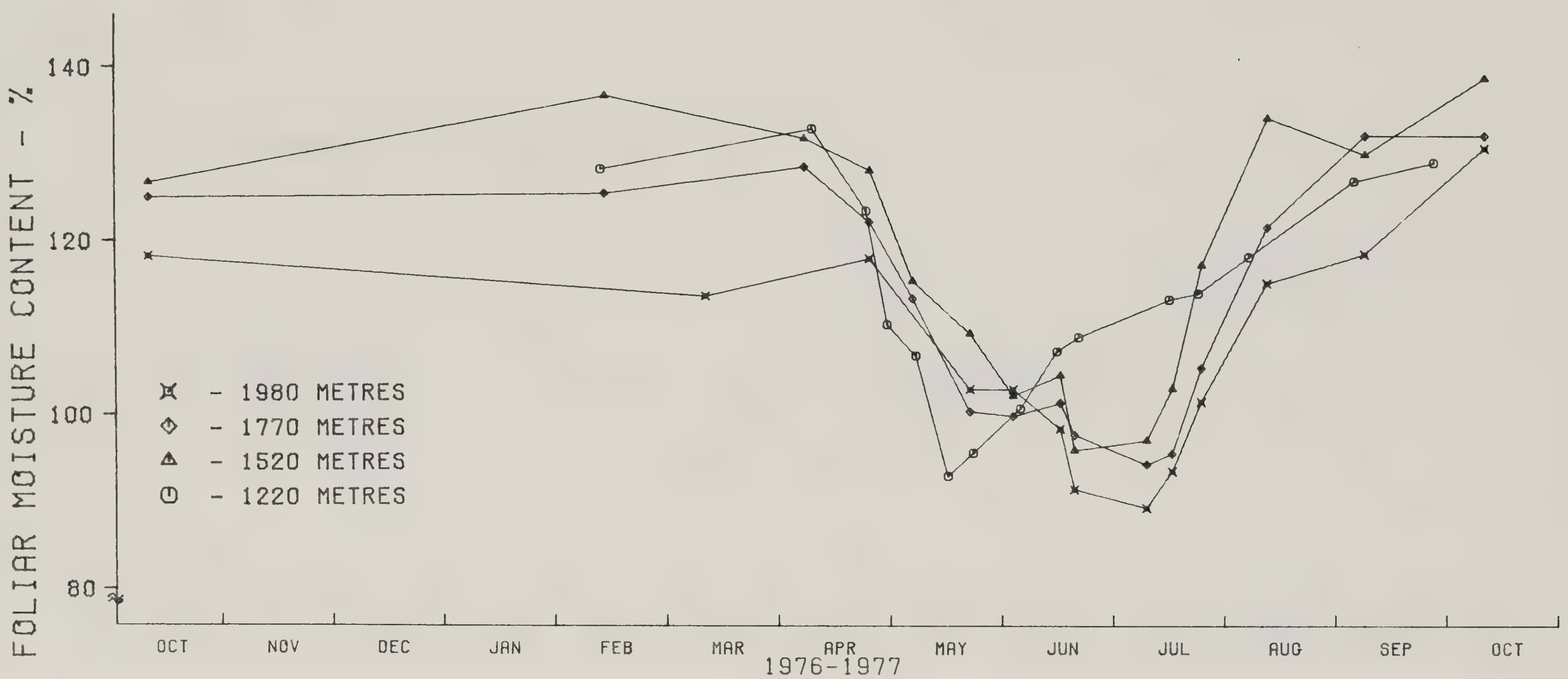


Figure 6. Foliar moisture content (dry weight moisture percent) of lodgepole pine at Swan Hills sampling locations (each plotted value is the mean of six observations).

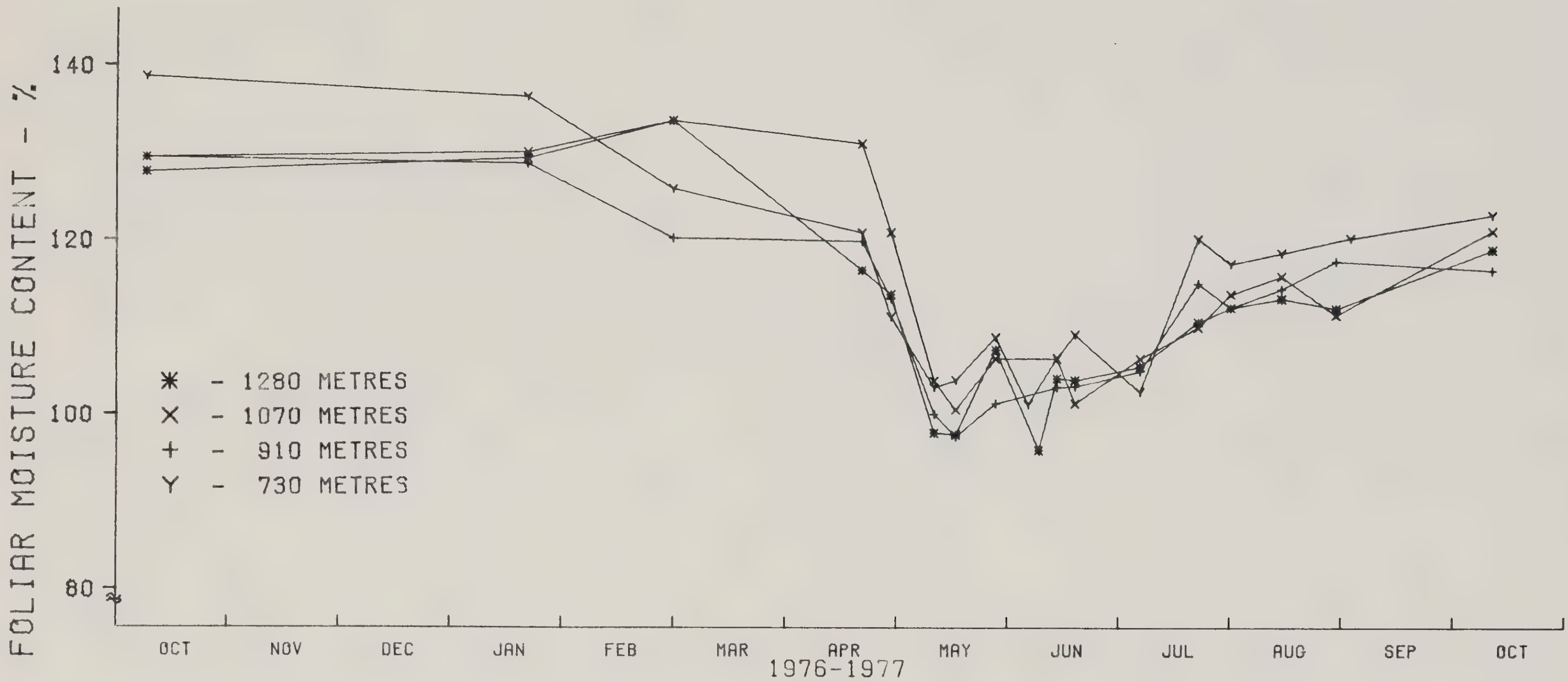
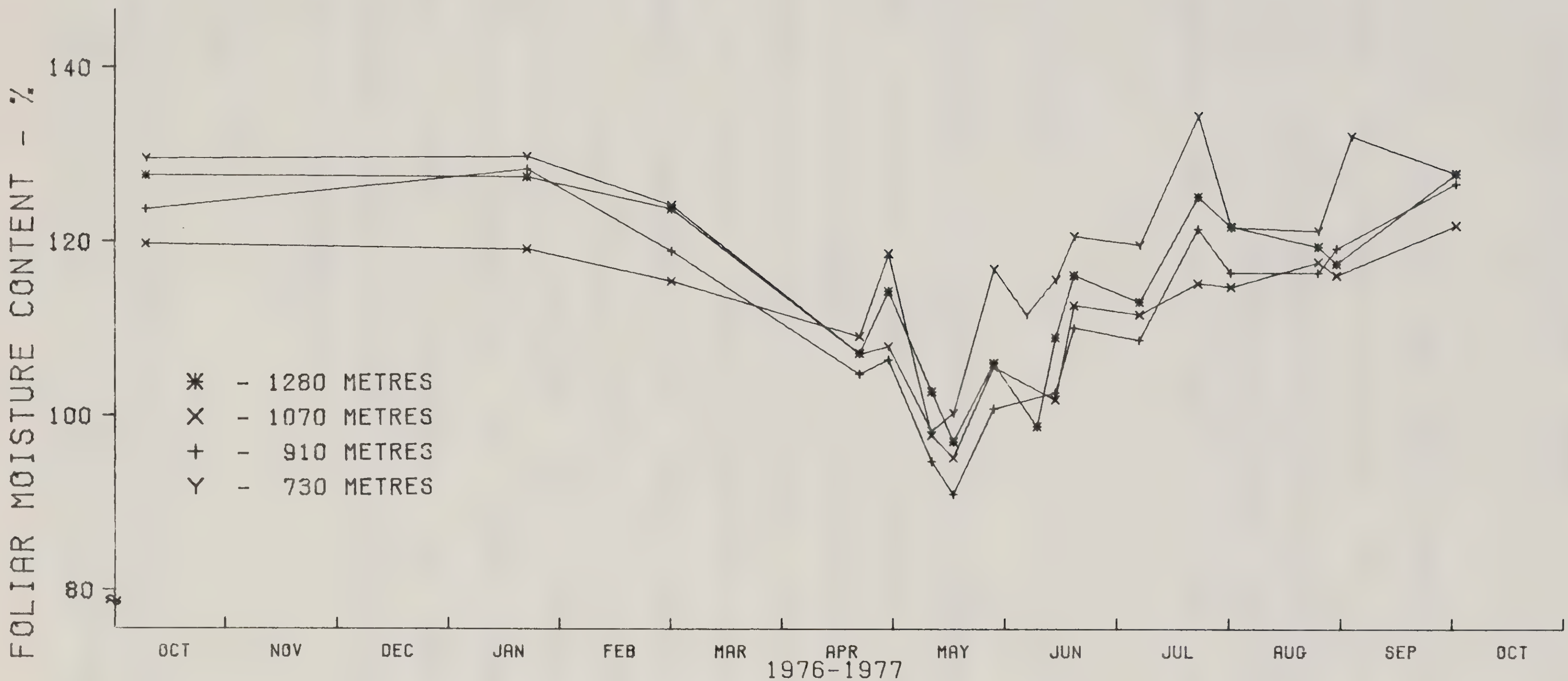


Figure 7. Foliar moisture content (dry weight moisture percent) of black spruce at Swan Hills sampling locations (each plotted value is the mean of six observations).



at low and mid elevations, but more rapid at high elevations.

Two-way analysis of variance was made possible by exclusion of the initial two sampling periods and one period in August to create one complete column and row. As shown in Table 2, fluctuation of foliar moisture content between periods (labeled Period) over the sampling interval was highly significant.

White-Engelmann spruce

The moisture content of white-Engelmann spruce foliage on foothills sampling locations (Figure 5) appeared to follow fluctuation patterns similar to lodgepole pine foliage on similar locations. Over-winter moisture contents appeared to have been somewhat less at treeline than at lower elevation sampling locations. The foliar moisture content minimum at mid-elevation (1520 m) was more pronounced than in the comparable lodgepole pine location, occurring at an intensity similar to the other spruce locations. As shown in Table 3, fluctuation of foliar moisture content between periods (labeled Period) over the sampling interval was highly significant.

Swan Hills lodgepole pine

The moisture content of lodgepole pine foliage on the Swan Hills sampling locations (Figure 6) was also relatively

Table 2. Two-way analysis of variance of foliar moisture content (dry weight moisture percent) for foothills lodgepole pine for sampling locations at five elevations and 15 periods (maximum selected to allow determination of interaction effect)

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio	Probability
Main effects	32770.5	18	1820.6	55.61	0.0%
Period	27472.8	14	1962.3	59.95	0.0%
Elevation	3729.8	4	932.4	28.49	0.0%
Interaction					
Per. x Elev.	5250.9	46	114.2	3.49	0.0%
Explained	38112.2	64	595.5	18.19	0.0%
Residual	10442.4	319	32.7		
Total	48554.5	383	126.8		

Table 3. Two-way analysis of variance of foliar moisture content (dry weight moisture percent) for foothills white-Engelmann spruce for sampling locations at four elevations and 14 periods (maximum selected to allow determination of interaction effect)

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio	Probability
Main effects	34933.4	16	2183.3	57.48	0.0%
Period	32434.5	13	2494.9	65.68	0.0%
Elevation	2819.2	3	939.7	24.74	0.0%
Interaction					
Per. x Elev.	4049.6	32	126.5	3.33	0.0%
Explained	39129.6	48	815.2	21.54	0.0%
Residual	7900.9	208	38.0		
Total	47030.4	256	183.7		

stable throughout the winter period. Spring moisture content declines began in late April, followed by minima characteristic of lower-elevation foothills sampling locations (Figure 4). The extreme minima points occurred in mid-May for 910 and 1040 m sampling locations and early-June for the 730 and 1280 m elevation locations. No corresponding samples for 910 and 1040 m locations were taken during this period due to weather limitations. Recovery from the minima was relatively slow in all cases.

Two-way analysis of variance (Table 4) revealed highly significant fluctuation (labelled Period) in lodgepole pine of the Swan Hills area.

Black spruce

The moisture content of black spuce foliage on Swan Hills sampling locations appeared to have been the most erratic (Figure 7). An apparent general spring decline was followed by temporary increases in foliar moisture content immediately before the rapid decline to extreme minima in mid-May. This was found to occur at all four sampling locations. The minima period was followed by apparently irregular recovery to normal moisture contents.

Two-way analysis of variance (Table 5) revealed highly significant fluctuation (labelled Period) in black spruce of the Swan Hills area.

Table 4. Two-way analysis of variance of foliar moisture content (dry weight moisture percent) for Swan Hills lodgepole pine for sampling locations at four elevations and 16 periods

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio	Probability
Main effects	33852.0	18	1880.7	45.02	0.0%
Period	33275.7	15	2218.4	53.10	0.0%
Elevation	1077.2	3	359.1	8.60	0.0%
Interaction					
Per. x Elev.	2447.0	43	56.9	1.36	7.3%
Explained	36659.5	61	601.0	14.39	0.0%
Residual	13284.4	318	41.8		
Total	49943.9	379	131.8		

Table 5. Two-way analysis of variance of foliar moisture content (dry weight moisture percent) for Swan Hills black spruce for sampling locations at four elevations and 16 periods

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio	Probability
Main effects	25927.8	18	1440.4	37.72	0.0%
Period	24453.5	15	1630.2	42.69	0.0%
Elevation	2498.9	3	833.0	21.81	0.0%
Interaction					
Per. x Elev.	2744.0	43	63.8	1.67	0.9%
Explained	30263.1	61	496.1	12.99	0.0%
Residual	9623.2	252	38.2		
Total	39886.2	313	127.4		

Variation between elevations

Differences found between foliar moisture content measured at elevational sampling locations (labelled Elevation in Tables 2 through 5) were highly significant for the three species of both areas. The significance of the interaction term (Per. x Elev.) for both foothills species (Tables 2 and 3) indicated independence of fluctuation between elevations, which therefore was a major source of the variation between the sampling locations (Elevation). As seen in Figures 4 and 5 and shown with Tukey's multiple comparison test in pages 129 to 132 of Appendix 3, the period of foliar moisture content minimum moves from May at low elevations to July at high elevations.

In the Swan Hills area the interaction term (Table 4) for lodgepole pine is not significant, implying that fluctuations in foliar moisture content are reasonably concurrent over the elevational range. With black spruce, however, the significant interaction term (Table 5) indicates, as with the foothills, independence of fluctuations between elevations. But, as shown in Figure 7 and pages 135 and 136 of Appendix 3 with Tukey's multiple comparison test, the fluctuation differences are more difficult to describe than with the foothills results.

Elevational effects on minimum timing

Graphical representation of the relationship between observed foliar moisture content and elevation is shown in Figures 8 through 13. The polynomial analysis of foliar moisture content data to detect significant trends related to elevation, as described in the methods section, is summarized in Table 6. The trend described in the methods section was evident in lodgepole pine foliage of the foothills sampling locations (Figure 8), although not apparent in the spruce species or in lodgepole pine of the Swan Hills.

In white spruce (Figure 9), the absence of a positive variation period may be an expression of possible underlying negative variation resulting from lower moisture at the treeline sampling location. The strong negative relationship during the late minimum period (during high elevation minima) may be a reflection of the described trend in part.

The absence of the described trend in the Swan Hills, for both lodgepole pine (Figure 10) and black spruce (Figure 11) may be the result of two possible factors. First, the elevational gradient may not have been large enough to statistically measure the trend as found with foothills lodgepole pine. Second, timing of the foliar moisture minimum period may not vary as strongly with elevational factors at lower elevations as it appears to with the higher

Figure 8. Isoquants of fcliar moisture content (dry weight moisture percent) of lodgepole pine at foothills sampling locations on elevation by date (each plotted value is the mean of six observations).

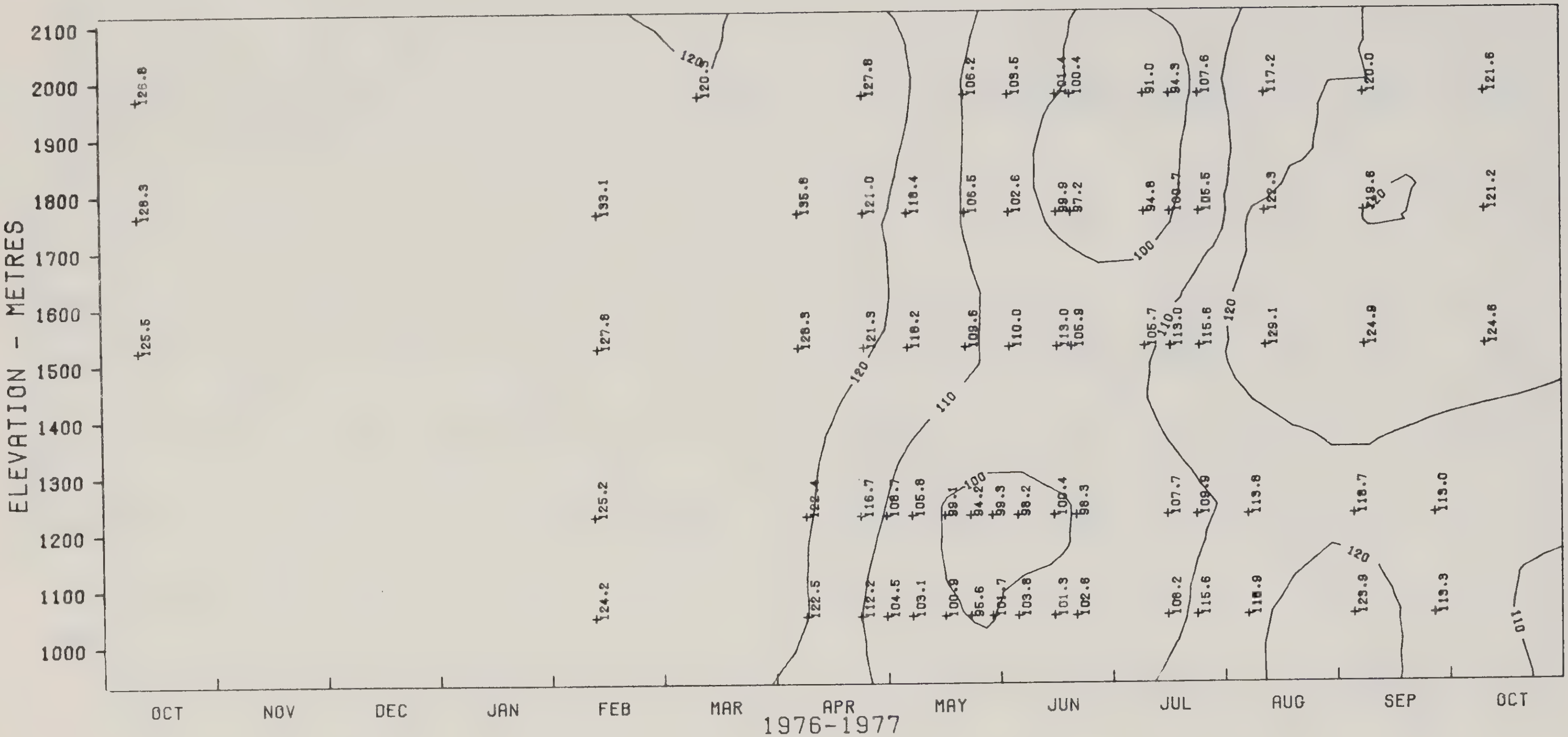


Figure 9. Isoquants of foliar moisture content (dry weight moisture percent) of white-Engelmann spruce at foothills sampling locations on elevation by date (each plotted value is the mean of six observations).

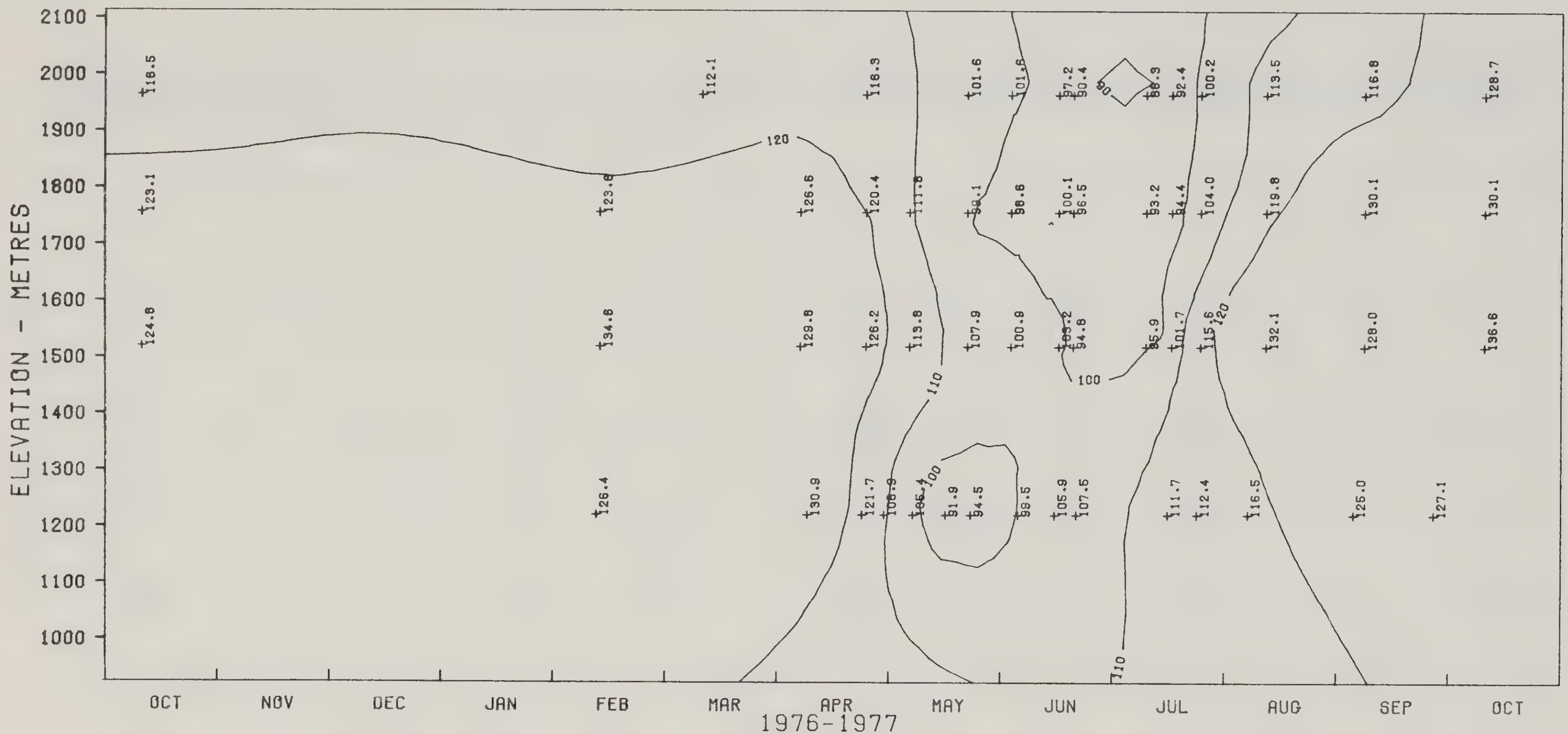


Figure 10. Isoquants of foliar moisture content (dry weight moisture percent) of lodgepole pine at Swan Hills sampling locations on elevation by date (each plotted value is the mean of six observations).

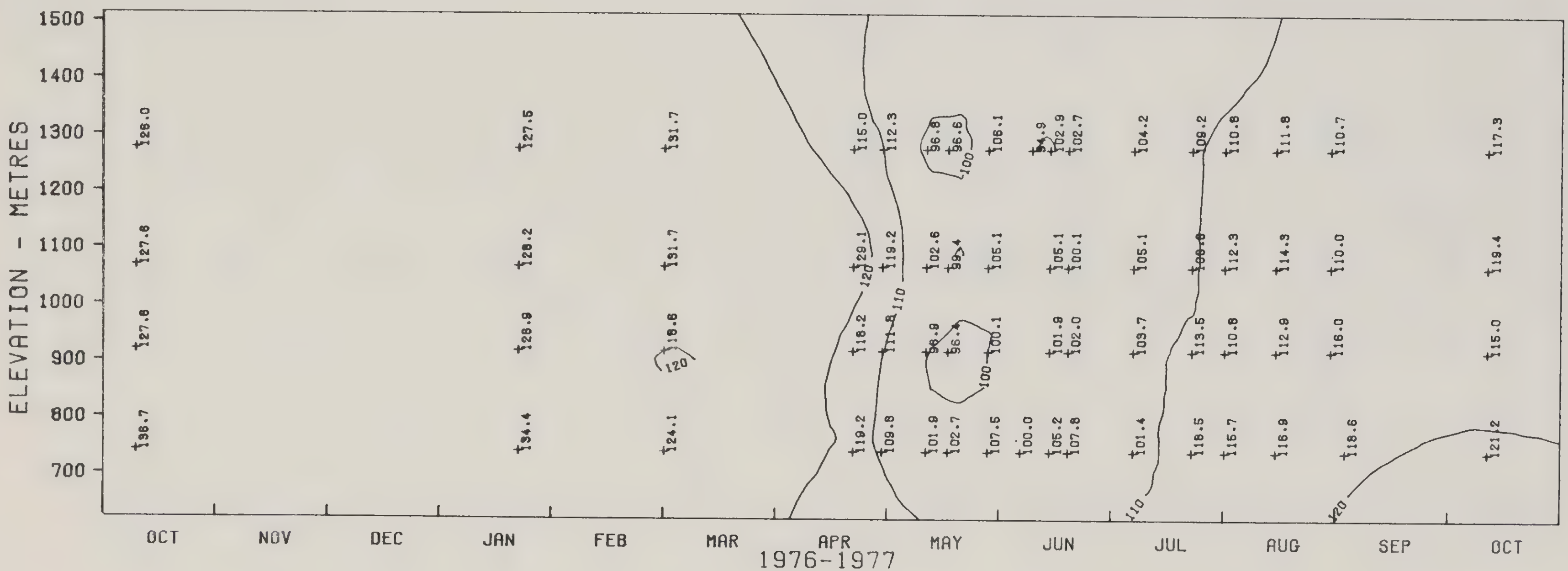


Figure 11. Isoquants of foliar moisture content (dry weight moisture percent) of black spruce at Swan Hills sampling locations on elevation by date (each plotted value is the mean of six observations).

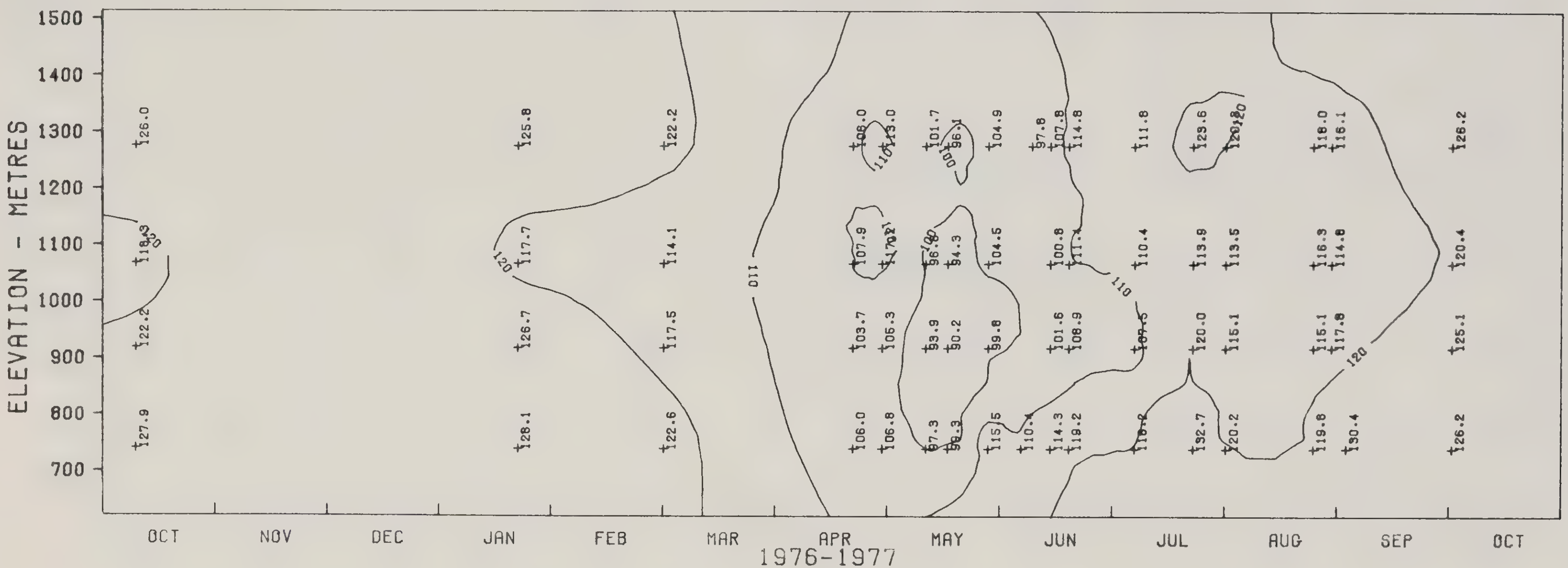


Figure 12. Isoquants of foliar moisture content (dry weight moisture percent) of lodgepole pine at both foothills and Swan Hills sampling locations on elevation by date (each plotted value is the mean of six observations).

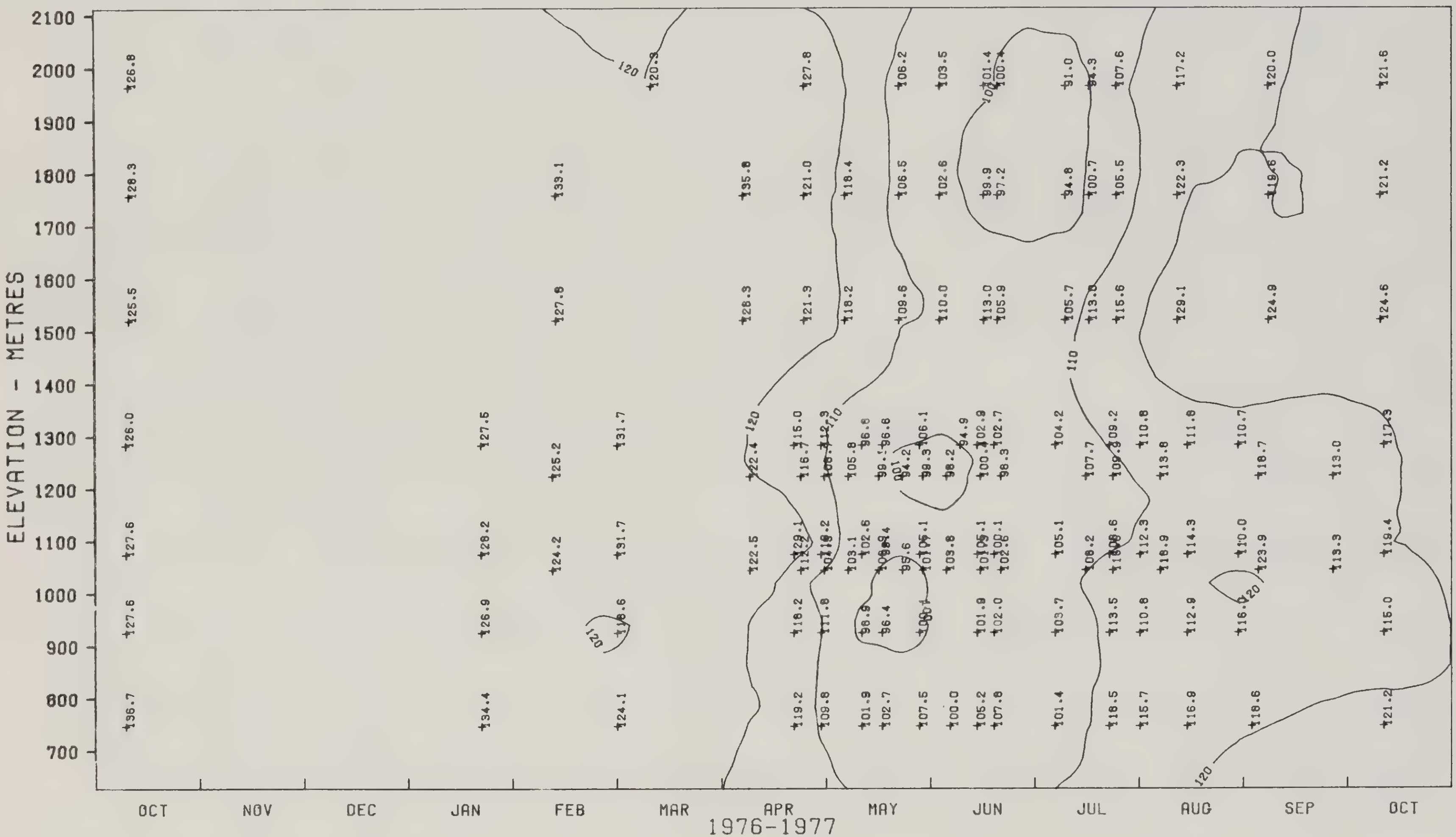


Figure 13. Isoquants of foliar moisture content (dry weight moisture percent) of lodgepole pine, white spruce and black spruce of foothills and Swan Hills sampling locations on elevation by date (sampling points shown).

Table 6. Summary of results of polynomial tests of foliar moisture content (dry weight moisture percent) by elevation. (Designation with a plus sign (+) indicates a significant ($p<5\%$) positive relationship between foliar moisture content and elevation, a minus sign (-) indicates a negative relationship. With the step-wise[1] quadratic test, a positive relationship indicates a lower mid-elevation foliar moisture content whereas a negative relationship indicates higher mid-elevation foliar moisture content. Significant deviation from linearity, marked with an asterisk, implies that foliar moisture content means cannot be adequately explained by elevation.)

		Polynomial Test Results							
Month	Sample	Linear				Quadratic			
		FPl[2]	FSw	SPl	SSb	FPl	FSw	SPl	SSb
1976 October					(-)*		[3]		(+)
1977 Jan-Feb		(-)			(-)*		[3]		(+)*
Mar-Apr			(-)*	(+)*		(-)	(-)		(+)
April		(+)						(-)*	
May	1	[3]	(-)*			[3]	[3]		
May	2	(+)							(+)
May	3	(+)*					(+)*		(+)
June	1		[3]		(-)*		[3]		(+)
June	2								(+)
June	3		(-)			(-)*			(+)
June	4		(-)						(+)
July	1	(-)				[3]	[3]		
July	2	(-)*	(-)		(-)*				(+)
August	1	(-)*	(-)						
August	2	(-)							
September			(+)	(-)	(-)*		(-)		(+)
Sept-Oct		(+)*					(-)		

[1] Testing whether the quadratic relationship significantly improves relationship determination ("goodness of fit")

[2] FPl - Foothills lodgepole pine
FSw - Foothills white-Engelmann spruce
SPl - Swan Hills lodgepole pine
SSb - Swan Hills black spruce

[3] Insufficient classes to allow test (<2 for linear, <3 for quadratic)

foothills sample results.

The incidence of positive quadratic variation in black spruce found over the sampling term is also worth noting (Table 6). Although this could result from site and/or stand conditions, no correlative parameters are apparent from the sampling location descriptions (Appendix 2). It would seem quite possible that this behavior was a result of diurnal variation affecting physiological factors. Sampling during the afternoon period (1230 to 1730 hours) resulted in lower moisture contents at mid-elevation sampling locations (910 and 1040 m). Absence of the same variation in lodgepole pine foliage collected from these locations would lead to speculation that site and stand conditions were not the main cause of the trend. The appearance of such a trend in black spruce in contrast to lodgepole pine of the same locations may be an expression of the relatively retarded physiological response to moisture loss specific to black spruce described by Mayo (1976) and van Zinderen Bakker (1974).

A further question arises as to the continuity of the moisture content minimum in lodgepole pine foliage from the lower Swan Hills to the upper foothills sampling locations. Shown in Figure 12, the minima period occurred in mid- to late-May at all low elevation locations (1219 m), except that at 730 m elevation where the minimum was delayed until June. At 1280 m an initial minimum period appeared in mid-

May to be succeeded by a slightly more intense minimum during early June. Similar minima periods also appear with 1524 m sampling location foliage, occurring late-May and late-June, respectively. This may suggest that the minimum period was not a continuous function of elevation, but may in fact have been a discrete or modal effect of short term weather and/or site conditions. This may also be speculated from a composite graph of the three coniferous species in Figure 13.

EFFECTS OF ASPECT

The hypotheses tested here statistically represent the specific locations sampled. Absence of true replication eliminates the possibility of estimation of the variation of foliar moisture content over other aspect locations in the study area.

Seasonal minimum occurrence

The seasonal variation of foliar moisture content, represented in the two-way analysis of variance in Table 7, is highly significant. (This was also the case with individual one-way analyses of variance performed for each aspect location.) Moisture content behaved similarily on all aspect locations (at 1280 m), as shown in Figure 14, closely resembling that encountered at the nearby 1220 m elevation sampling location for lodgepole pine (Figure 3). The observed minimum values appeared in late-May for all aspects

Figure 14. Foliar moisture content (dry weight moisture percent) of lodgepole pine on four aspects at a sampling location of the foothills (each plotted value is the mean of six observations)

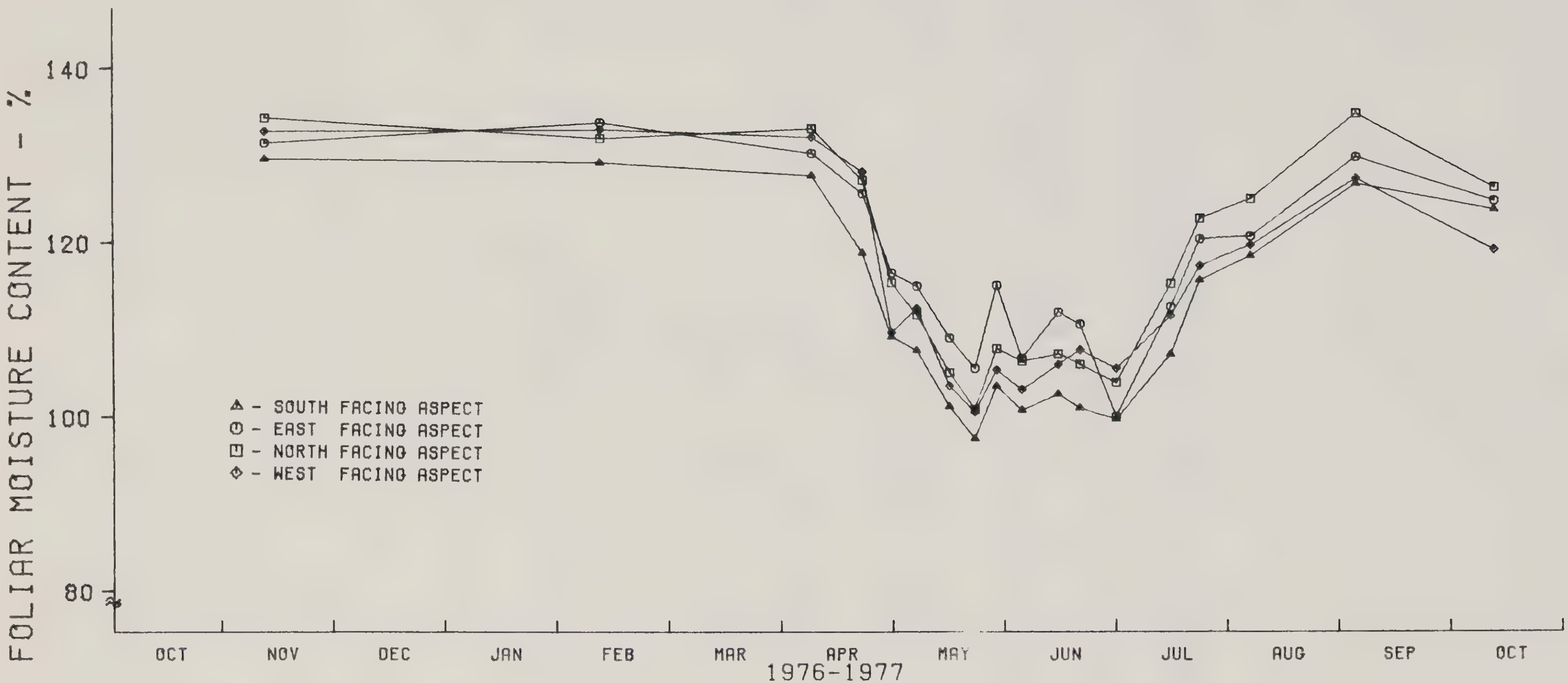


Table 7. Two-way analysis of variance of foliar moisture content (dry weight moisture percent) measured in lodgepole pine over four aspects and 18 periods

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio	Probability
Main effects	48139.9	20	2407.0	70.40	0.0%
Period	46019.1	17	2707.0	79.20	0.0%
Aspect	1993.3	3	664.4	19.44	0.0%
Interaction					
Per. x Asp.	1429.4	51	28.0	.82	80.5%
Explained	49519.8	71	679.5	20.41	0.0%
Residual	12134.0	355	34.2		
Total	61653.8	426	144.7		

except the east-facing location where a secondary minimum is more pronounced in early July. The reoccurrence of secondary minima on all locations at this time may indicate some dependence on short-term weather effects, perhaps in this case effected through local environmental conditions.

Variation between aspect locations

There is a highly significant difference between the moisture contents found at the four aspect locations over the sampling periods (Table 7). As the interaction with periods is not significant, this would mean that the difference found was likely statistically consistent over the sampling duration, with some aspects having had consistently lower or higher moisture content than others. The south location exhibited the lowest moisture content, succeeded by west, north and east, respectively. Tukey's multiple comparison test demonstrated significance during 2 of the 18 sample periods (11.1%), as shown on pages 137 and 138 of Appendix 3. It is important to note again, however, that these results apply only to the specific locations sampled.

Dependence of seasonal fluctuation on aspect

The interaction term (period x aspect) is insignificant (Table 7), indicating that the moisture contents found on these locations follow reasonably parallel behavior despite differences in observed values. The absolute minimum date

for the east facing location which did not conform to the other aspects (Figure 14), is likely an incidental expression of natural variability in foliar moisture content.

SUMMARY - SEASONAL FLUCTUATION OF FOLIAR MOISTURE CONTENT

The minimum spring foliar moisture content was found to occur with all species on all sampling locations. Characteristics of the minimum period, however, did vary both with species and elevation, although not with aspect.

In lodgepole pine the minimum period began with a pronounced decline in foliar moisture at low elevations to a more gentle decline at higher elevations. Following the mid-spring minimum at elevations lower than 1520 m and early-summer minima above this, the recovery at all elevations was generally steady, terminating in mid-August in most cases, thus occurring more rapidly at the upper elevations.

In white-Engelmann spruce, the behavior of foliar moisture content closely paralleled that in lodgepole pine of corresponding elevations. One possible exception was with the foliage of treeline Engelmann spruce (nearing the krummholtz form), which appeared to have a lower moisture content than that of neighboring lodgepole pine for the entire season. This occurred despite similar water potentials observed during the spring and summer seasons

measured by Richards (1977), which may imply a difference in leaf or cellular structure in treeline Engelmann spruce.

The foliar moisture content variation most difficult to describe was that of black spruce. The apparently larger degree of short-term fluctuation observed may have been an expression of the lower leaf resistance response in black spruce described by Mayo (1976). This autecological characteristic may also be responsible for the moisture content decline during the abnormally warm early-spring period. The initial peak in black spruce foliar moisture prior to the observed minimum has also been observed by van Zinderen Bakker (1974) as a short-term increase in water potential although no speculation has been ventured as to its cause.

CONCOMITANT DATA RESULTS

The following are results of the concomitant data collection. Also included are discussions of the apparent relationship to foliar moisture content fluctuation and the concurrence with other findings.

Soil temperature

The soil temperatures found during the early minimum period, presented graphically in Appendix 4 (Figures 32, 33 and 34), appeared to follow the mean temperatures described by Clayton *et al.* (1977). Summarized in Table 8, the soil

Table 8. Estimated date and magnitude of minimum foliar moisture content and corresponding soil temperatures at two depths (95% conf. int. for temperatures are 3.1±1.4° C at 15 cm and 2.2±1.0° C at 30 cm, depths respectively)

Elevation (metres)	Estimated Foliar Moisture[1] Content Minimum Date	Value (%)	Soil Temperature[2] 15 cm. (Degrees Celcius)	30 cm.
Foothills lodgepole pine				
1040	May 26	95.	4.	3.
1220	May 26	94.	2.	1.
1520	June 27[1]	100.	2.[2]	0.[2]
1770	July 10[1]	93.	4.[2]	3.[2]
1980	July 15[1]	90.	3.[2]	3.[2]
White - Engelmann spruce				
1220	May 19	91.	1.	-1.
1520	June 23	94.	1.	0.
1770	July 13	93.	4.	3.
1980	July 13	88.	3.	3.
Swan Hills lodgepole pine				
730	June 09	100.	9.	8.
910	May 20	96.	3.	3.
1070	May 20	99.	1.	0.
1280	June 12[1]	95.	6.[2]	6.[2]
Black spruce				
730	May 16[1]	95.	4.[2]	2.[2]
910	May 18[1]	90.	3.[2]	3.[2]
1070	May 18[1]	92.	1.[2]	0.[2]
1280	May 20[1]	96.	1.[2]	1.[2]
Aspect locations (lodgepole pine)				
South	May 26	96.	3.[2]	2.[2]
East	July 04	99.	6.	4.
North	May 26	100.	2.[2]	1.[2]
West	May 26	99.	3.[2]	2.[2]

[1] Interpolated from trends where minimum appears to fall between observations

[2] Extrapolated or interpolated for estimated dates of foliar moisture content minima

temperatures found during the foliar moisture content minimum periods for the sampling locations are significantly above thawing (0° C). At an average of 3.1° C at 15 cm and 2.2° C at 30 cm depths, respectively, this data indicates that if soil temperature is a factor in foliar moisture content behavior, the critical temperature may lie between 0° C as used by Stashko and McQueen (1973) and 5° C as suggested by Richards (1977).

Phenological development

Development of vegetative and reproductive shoots, as shown in Appendix 5 (Figures 35 through 39), occurred generally as described in the literature. Development of male strobili in white-Engelmann spruce, however, was not detected, perhaps due to the lack of warm late-spring weather, as suggested by Fraser (1962). Black spruce was able to produce reproductive buds, concurring with the suggestion by Fraser (1966), of a dependence on warm early-spring conditions. However, appearance of the strobili in mid-May more closely follows observations by Moir and Fox (1975) with sitka spruce than those of Fraser (1966) with black spruce.

Flushing dates for vegetative buds concurred reasonably well with observations in the references. Lodgepole pine needles flushed in late-May to early-June, generally about 2 weeks after male strobili development, which is comparable

with dates for jack pine presented by Curtis and Popham (1972). Black spruce vegetative buds burst in late-May and early-June as well, only slightly later than the dates observed by Fraser (1966). White spruce was later than black spruce, however, flushing in early June, about three weeks later than observations by Fraser (1962).

The dependence of flushing dates on elevation (Table 9) is not apparently very strong. Reproductive bud development appeared to have been delayed about 12 days over the entire elevational gradient in lodgepole pine (730 to 1980 m) and about 4 days in black spruce (730 to 1280 m). Vegetative bud flushing was delayed about 14 days in lodgepole pine, 7 days in white-Engelmann spruce (1220 to 1980 m) and 9 days in black spruce.

Any relationship between physiological development and foliar moisture minimum timing, as reported by Russell and Turner (1976), was not apparent. While bud development is delayed up to 2 weeks from low to high elevations, the delay in foliar moisture content minimum is closer to 7 weeks. At higher elevations, the foliage is nearly full grown in both lodgepole pine and Engelmann spruce when the minimum occurs, implying that if the foliar moisture content change is in fact a buildup of photosynthate, it is not likely for the purpose of translocation to growing leaf meristems as proposed by Little (1973).

Table 9. Physiological development of male strobili and vegetative (terminal) buds with respect to minimum foliar moisture content observations

Elevation (metres)	Estimated Flushing Date[1] Male Strobili	Terminal Buds	Estimated Date of Foliar Moisture Content Minimum	Foliage Length at Min.
Foothills lodgepole pine				
1040	May 15	May 26	May 26	0 mm
1220	May 18	May 27	May 26	0 mm
1520	May 20	May 27	June 27	12 mm[2]
1770	May 20	June 04	July 10	22 mm[2]
1980	May 22	June 05	July 15	12 mm[2]
White - Engelmann spruce				
1220	---[3]---	June 03	May 19	0 mm
1520	---[3]---	June 10	June 23	12 mm
1770	---[3]---	June 10	June 13	16 mm
1980	---[3]---	June 10	June 13	18 mm
Swan Hills lodgepole pine				
730	May 10	May 22	June 09	12 mm[2]
910	May 12	May 23	May 20	0 mm
1070	May 12	May 26	May 20	0 mm
1280	May 12	May 26	June 12	7 mm
Black spruce				
730	May 12	May 28	May 16	0 mm
910	May 13	June 03	May 18	0 mm
1070	May 14	June 04	May 18	0 mm
1280	May 16	June 05	May 20	0 mm
Aspect locations (lodgepole pine)				
South	May 18	May 27	May 26	0 mm
East	May 19	May 27	July 04	25 mm
North	May 14	May 27	May 26	0 mm
West	May 20	May 27	May 26	0 mm

[1] Estimated as bud scale separation for 50% of buds
[2] Interpolated for estimated dates of foliar moisture content minima
[3] Insufficient bud formation to allow determination

The effect of aspect on phenological development was also not very strong. Reproductive development was only slightly earlier on the north facing aspect (May 14) than the other aspects (May 18 to 20). No difference in the development of vegetative buds was found between aspects, however.

Air temperature

The observed maximum and minimum air temperatures are shown in Table 10. Minimum temperatures were generally higher in Swan Hills as indicated by Patching (1977), however, the maximum temperatures were quite comparable for both areas. The temperature at the foliar moisture content minima for the species sampled was not consistent. Minimum temperatures at the minima ranged from about -3°C in the Swan Hills and lower foothills to +1°C in the upper foothills. Maximum temperatures ranged from 14 to 26 °C over both sampling areas.

CORRELATION ANALYSIS

Soil temperature was found to be the only concomitant variable possibly useful for regression analysis. Both Richards (1976) and Stashko and McQueen (1973) suggested that foliar moisture content might be correlated to soil temperature. From a review of the data it was felt that a quadratic regression model would serve as a reasonable measure of this relationship. Using a step-wise analysis

Table 10. Maximum and minimum air temperatures recorded at the sampling locations with comparative foliar moisture content minima dates (designation with P indicates lodgepole pine minima; S - white-Engelmann spruce in foothills, and black spruce in Swan Hills; B - both pine and spruce species at that location)

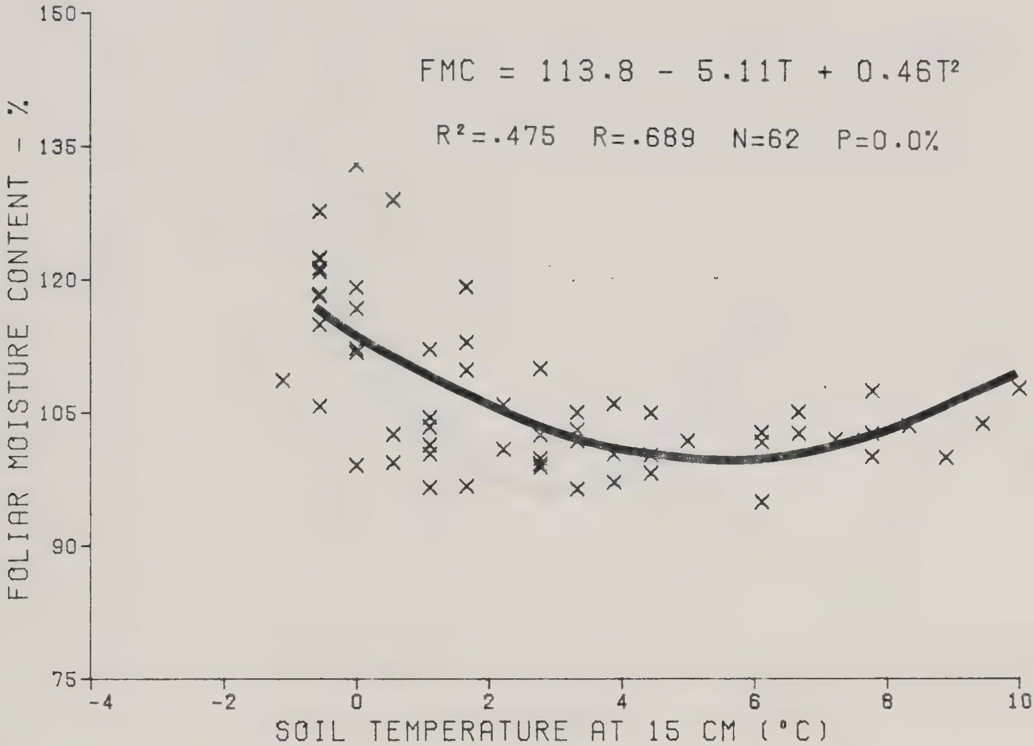
		Elevational Sample Location (elevation - tens of metres/species)										
		Swan Hills				Foothills						
Month	Sample	73	91	107	128	104 Pl	122 Pl	122 Sw	152 Pl	152 Sw	177	198
1977		Minimum Air Temperature (°C)										
Mar-Apr						-19	-18	-17				
April	1	-17	-17	-19	-18	-6	-10	-9	-16	-13		-14
April	2	-5	-5	-21	-19	-5	-5	-3				
May	1	2		-6	-3	-1	-5	-2	-2	-5	3	
May	2	-2S	-3B	-3B	-4S	-4	-5	-5				
May	3					-3P	-3P	-1S	-5	-8	-5	-5
June	1	4P	0	-1	-4P	-1	-2	-1				
June	2	5	-1	0	4	-3	-4	-2	1	-2	0	-1
June	3					-2	-1	-1	0	-1	0	-2
June	4	9	7	6	7	-1	-1	0	-1	0S	-2	
July	1	4	-4	-1	4				0P	-1	1B	1B
July	2					-1	-1	-1	-1	-2	1	1
July	3	5	2	1	5	1	-1	1	3	1	7	5
August	1		2	0	2							
August	2		-4	-4	2	1	0	1	0	0	3	1
September			-4	-4	2	-3	-3	-3	-3	-3	-1	-2
October			-7	-13	-16	-4		-3	-15	-14	-7	-7
		Maximum Air Temperature (°C)										
Mar-Apr						25	20	21				
April	1	35	31	27	24	31	28	29	23	23		21
April	2	31	32	25	27	30	28	29				
May	1	27		26	21	20	19	23	18	19	18	
May	2	21S	21B	14B	19S	21	19	20				
May	3					18P	18P	26S	17	16	26	17
June	1	25P	24	18	18P	26	20	22				
June	2	28	36	29	19	33	33	36	28	28	18	22
June	3					29	26	29	29	29	27	28
June	4	32	32	29	18	31	28	32	25	26S	25	
July	1	32	29	25	24				23P	22	21B	23B
July	2					24	24		19	23	19	18
July	3	33	33	28	27	32	26	31	25	29	24	28
August	1		32	27	26							
August	2		21	23	17	3	28	33	18	25	23	22
September			28	24	22	30	27	30	26	26	23	25
October			19	19	20	24		19	20	19	20	16

(including f-test), highly significant (P<1%) correlations were found for shallow (15 cm) soil temperature as a correlate in foliar moisture content variation with all three species, and for deep (30 cm) soil temperature with lodgepole pine and black spruce. White spruce was significant to P<5%. The regression formulae and plots are displayed in Figures 15, 16 and 17.

SUMMARY - FOLIAR MOISTURE CONTENT BEHAVIOR FACTORS

It is possible that several environmental factors may influence foliar moisture content as indicated in the literature and collected data. Soil temperature appears to be a correlate accounting for approximately 40 to 60% of spring-time foliar moisture content variation, as indicated from the r^2 values. Other short-term environmental factors may also contribute. Refinement of foliar moisture content modelling would depend on further investigations of these and other possible factors.

Figure 15. Plotted values of observed foliar moisture contents (dry weight moisture percent) vs soil temperatures measured at 15 and 30 cm depths, respectively, for lodgepole pine (with regression formulae, coefficients (R), sample size (N) and f-probability (P)).



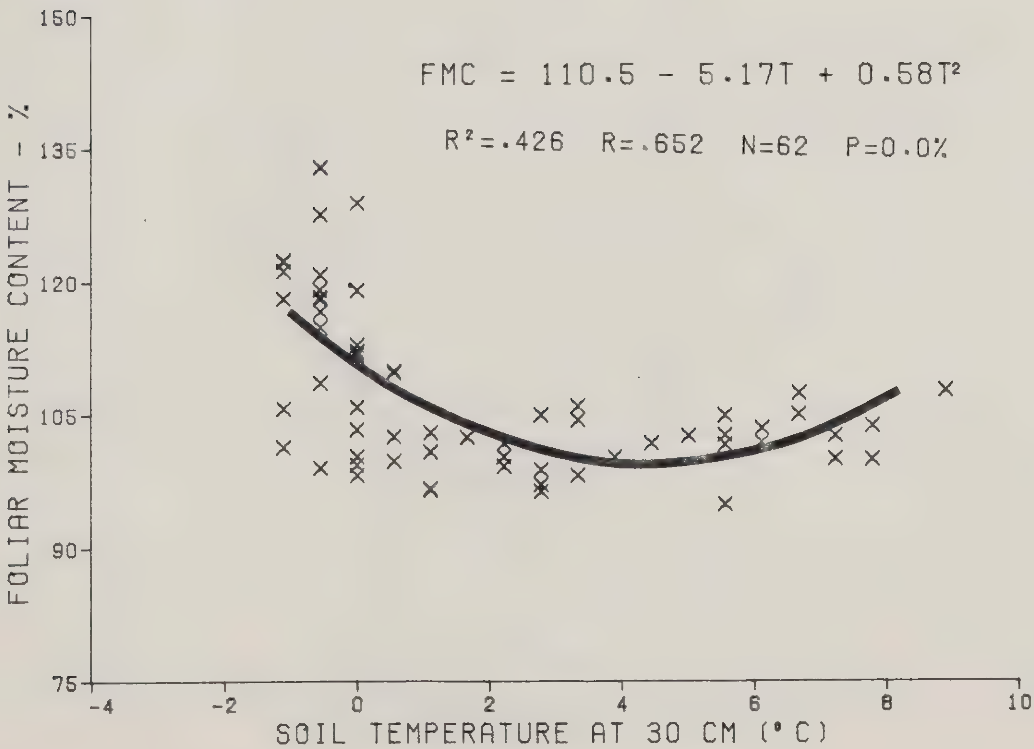
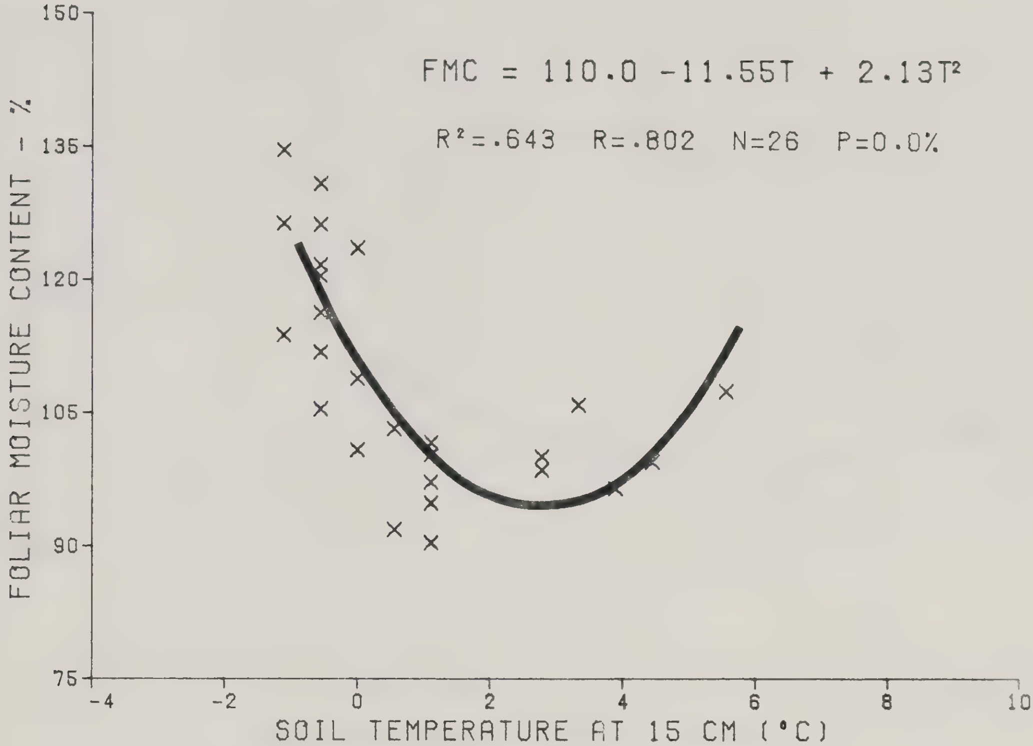


Figure 16. Plotted values of observed foliar moisture contents (dry weight moisture percent) vs soil temperatures measured at 15 and 30 cm depths, respectively, for white spruce (with regression formulae, coefficients (R), sample size (N) and f-probability (P)).



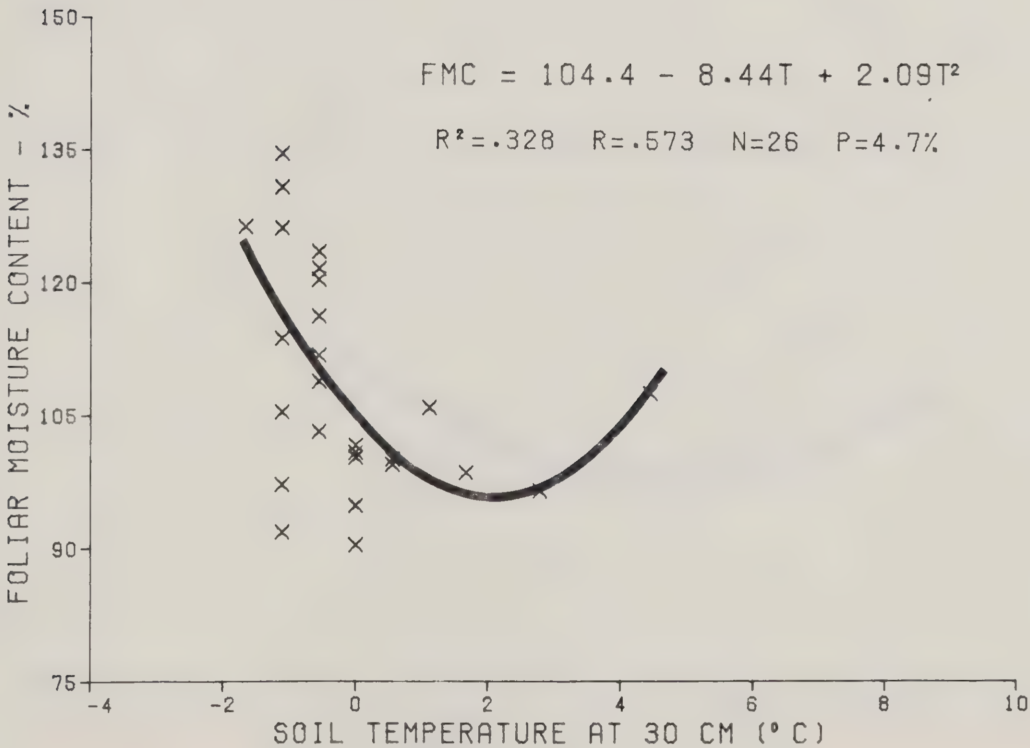
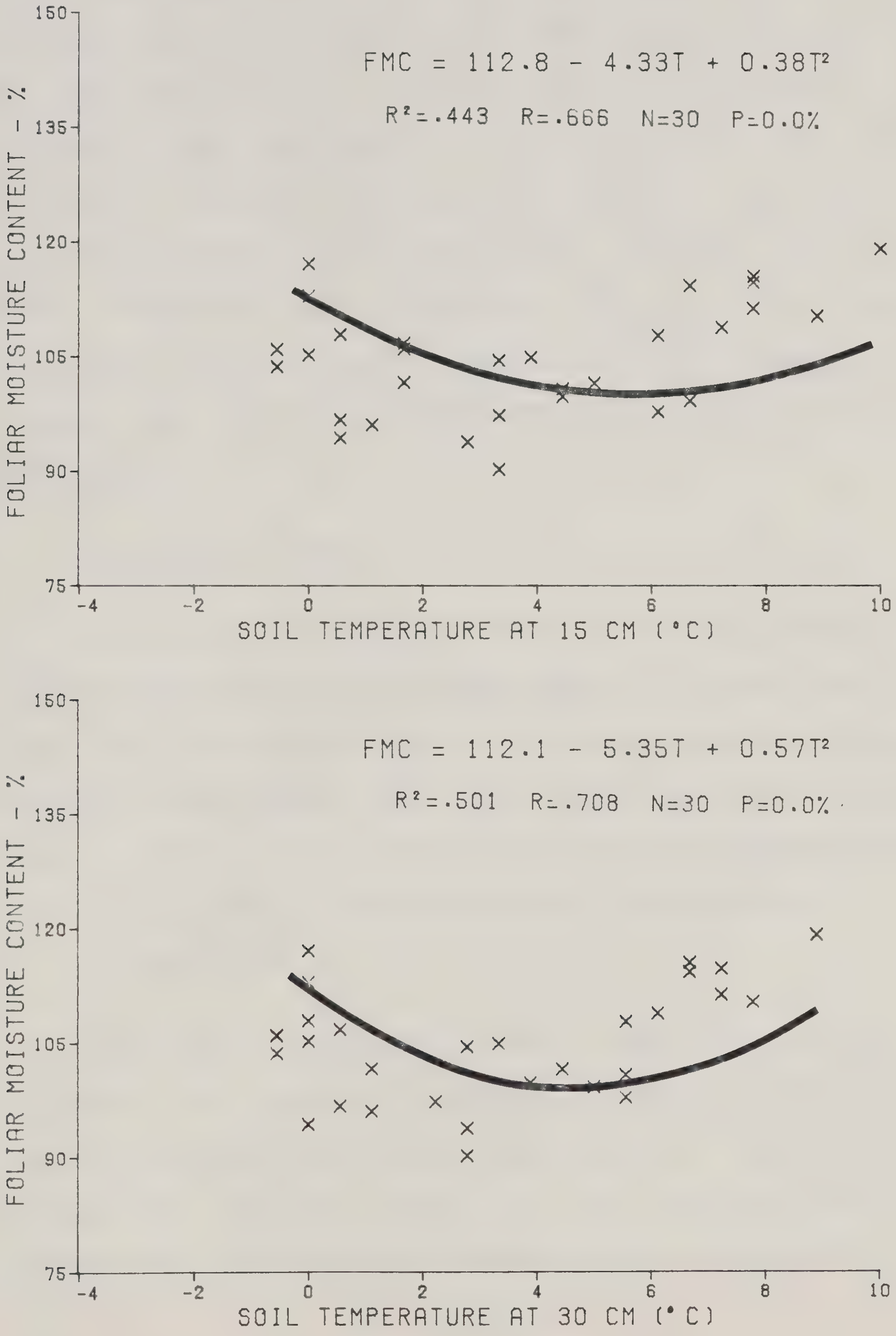


Figure 17. Plotted values of observed foliar moisture contents (dry weight moisture percent) vs soil temperatures measured at 15 and 30 cm depths, respectively, for black spruce (with regression formulae, coefficients (R), sample size (N) and f-probability (P)).



CHAPTER VI

IMPLICATIONS IN CROWN FIRE OCCURRENCE

This chapter deals with the application of foliar moisture content patterns to the occurrence of crown fires in the study area. A major limitation entering into this anlysis is the availability of information. The records provided adequate information on the occurrences and locations of obvious crowning fires. However, due to the less accurate data available on crown fire behavior parameters, such as rate of spread and fire intensity, this analysis was limited to discussion of patterns of crown fire occurrence.

CROWN FIRE THEORY

One of the leading works which attempts to describe the relationship of foliar moisture content to crown ignition is that of van Wagner (1977). In his theory of crowning initiation, he states that the heat of ignition for foliage (h) in kJ/kg, is primarily dependent on moisture content (m - as dry weight moisture percent), derived as:

$$h = 460 + 26m$$

This heat of ignition is then used to describe the intensity of surface fire required to ignite given crowns, herein referred to as crown ignitibility. Ignitibility is defined by Anderson (1970) as the ignition delay time, namely that ignitibility increases as the exposure to the

ignition source decreases. For our purposes this will be further interpreted to mean that ignitibility also determines the level of intensity necessary to induce ignition. Using Byram's (1959) equation, the required intensity (Io) is expressed as a function of crown base height (z) and heat of ignition:

$$Io = (C \cdot z \cdot h) \exp(3/2)$$

where: C, a constant, is empirically estimated as 0.010 where: Io is expressed in kW/m and z is expressed in metres.

Essentially, this intensity is that of a surface fire which would be required to ignite a crown of given moisture content and crown base height.

Application of van Wagner's theory to describe the incidence of crown fires as expected from the collected data was used to model crown ignitibility. The driving variables for the model were crown base height (to the live crown) and foliar moisture content. It was assumed that the foliar moisture content described in the theory represented that of the entire crown, rather than that of the 1976 needles alone. This is discussed in a following section. The output of this model of crown ignitibility (in terms suited to the available fire information) was then compared to actual crown fire occurrence to give a general indication of the validity of the model.

The most appropriate description of surface fire

intensity available with the fire records is the Canadian Fire Weather Index (van Wagner 1974(b)) or FWI. The FWI is an open ended scale which has been constructed from studies of fire intensities of Ontario red pine fuels using weather parameters as the driving variables, in a model to describe the intensity potential of surface fuels. The relationship with intensity is (adapted from van Wagner 1974(b)):

I = Cm•(10(exp(.2(e(exp(1.55(ln(1.63(ln(FWI)))))))))))

where: I is intensity in kW/m

Cm is a metric conversion factor

(3.46 kW•ft•sec/BTU•m)

or conversely:

FWI = e(exp(.614((4.9(log(I/Cm))) exp(.647))))

To test the hypothesis of correlation between the FWI and measured fire intensity, results of the Darwin Lake Study (Quintilio, et al. 1977) were used. From the observed fire intensities, the FWI was calculated using the function above. The comparison of actual on-site FWI values to those calculated shows a significant relationship and yields the regression formula as presented in Table 11.

To illustrate how van Wagner's theory would relate to a simplified model of coniferous ignitibility, Figures 18 and 19 were constructed. They show the relationship of foliar moisture content of crowns of different base heights to surface fire intensity which would be required to ignite them. These are expressed as the FWI that would correlate to

Figure 18. Coniferous ignitibility model: graph of base height of ignitable crowns under fire weather index and foliar moisture content (dry weight moisture percent) conditions.

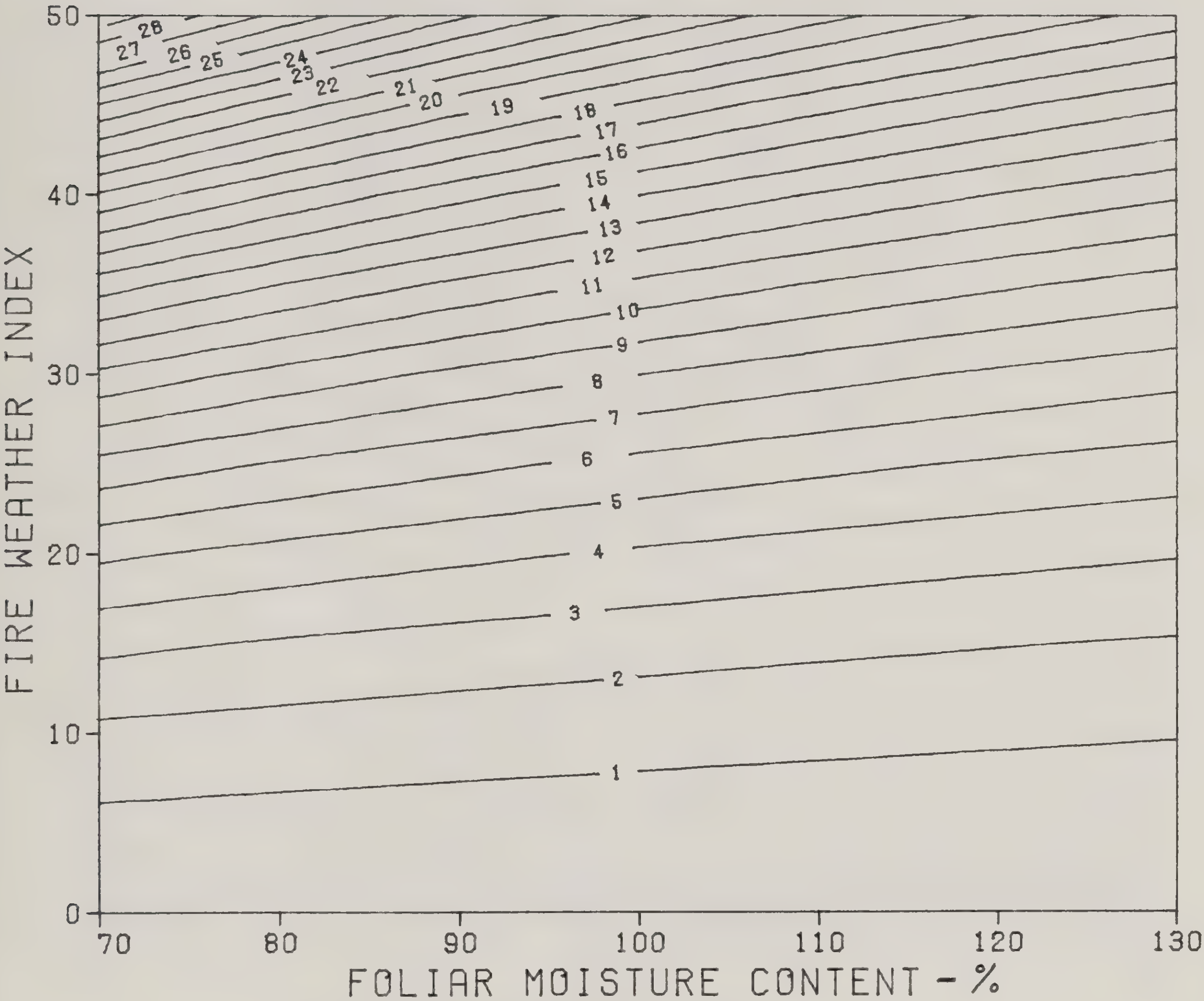


Figure 19. Coniferous ignitibility model: graph of fire weather index required to ignite crowns of a given base height and foliar moisture content (dry weight moisture percent).

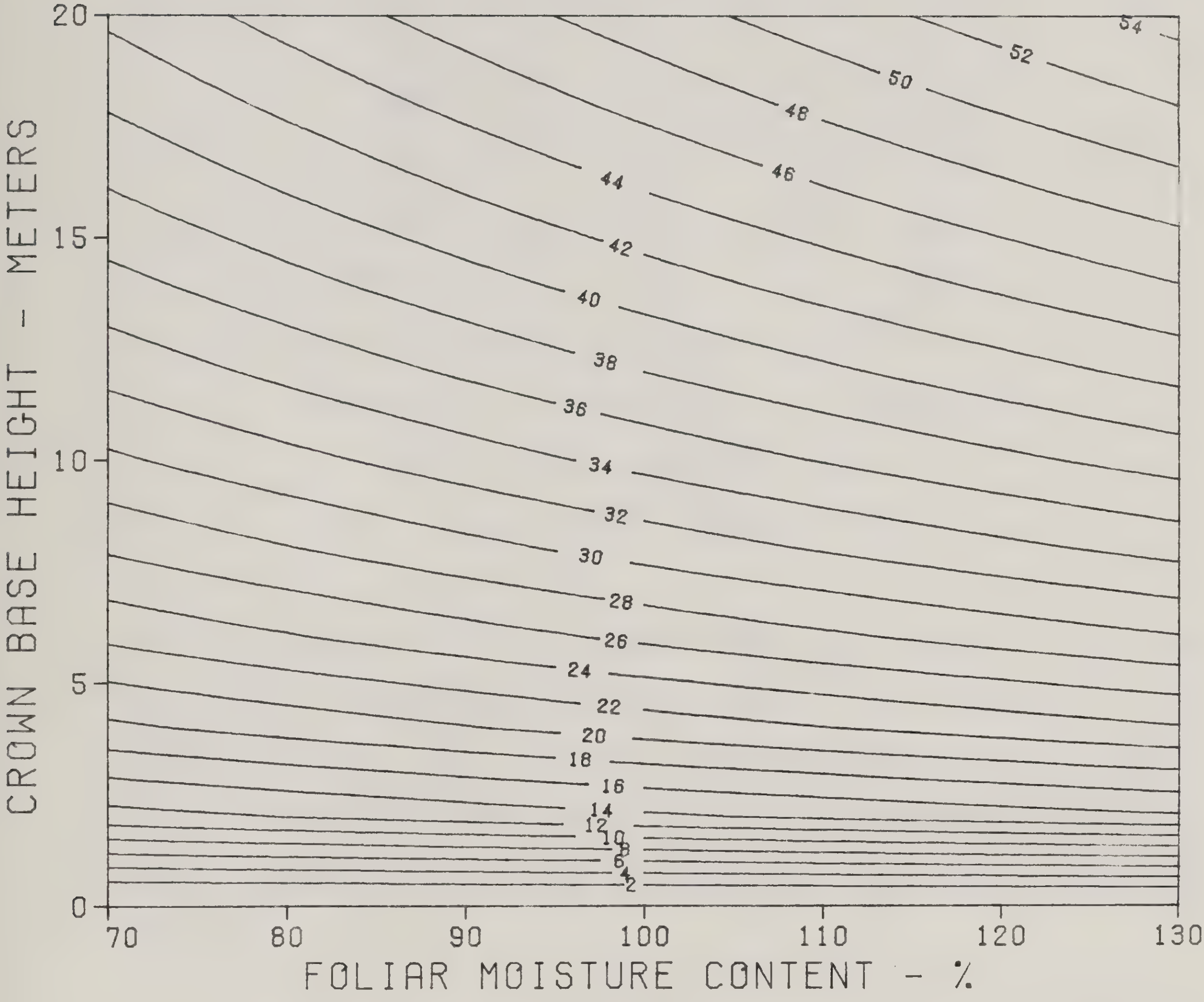


Table 11. A comparison of measured surface fire intensity to measured and estimated Canadian Fire Weather Index for five surface fires at Darwin Lake Alberta, 1975 (from: Quintilio, et al. 1977)

Intensity (kW/m)	FWI (on site)	FWI (estimated)
670	14	18.7
950	17	21.3
1900	21	27.0
1230	23	23.3
6150	33	39.6
r=.95	r^2=.91	sig=1.0%

FWI = .93•(estimated) - 2.4

fuels similar to those at Darwin Lake and having that energy potential. Using this representation of the theory it is apparent that the natural variation in crown base height would allow for a much greater effect on required intensity (FWI values) than would the observed variation in moisture content.

Application of this model to describe the ignitibility effects of the observed moisture contents was complicated by this crown base height factor. In order to produce realistic but unobscured representation of the areas sampled, the crown base heights in Table 12 were used as standardized

values, adapted from those actually observed on the study plot (see Appendix 2).

Table 12. Standardized crown base heights used in crown ignitibility model (adapted from observed crown base heights)

Elevation metres	730	910	1040	1070	1220	1280	1520	1770	1980
Lodgepole pine	5.0m	5.0m	5.0m	5.0m	5.0m	5.0m	5.0m	4.0m	2.0m
White-Engelmann spruce					2.5m		2.5m	2.0m	1.0m
Black spruce	1.5m	1.5m		1.5m		1.5m			

OVERALL FOLIAR MOISTURE CONTENT ESTIMATION

Application of the foliar moisture content data in terms related to the model required approximation of the moisture content of the foliage of the entire crown. Since samples were restricted to 1976 foliage alone, adjustments were needed. Corrections were necessary for at least two other factors: 1) an adjustment (negative) for moisture content of old (pre-1976) foliage and, 2) an adjustment (positive) for new (1977) foliage.

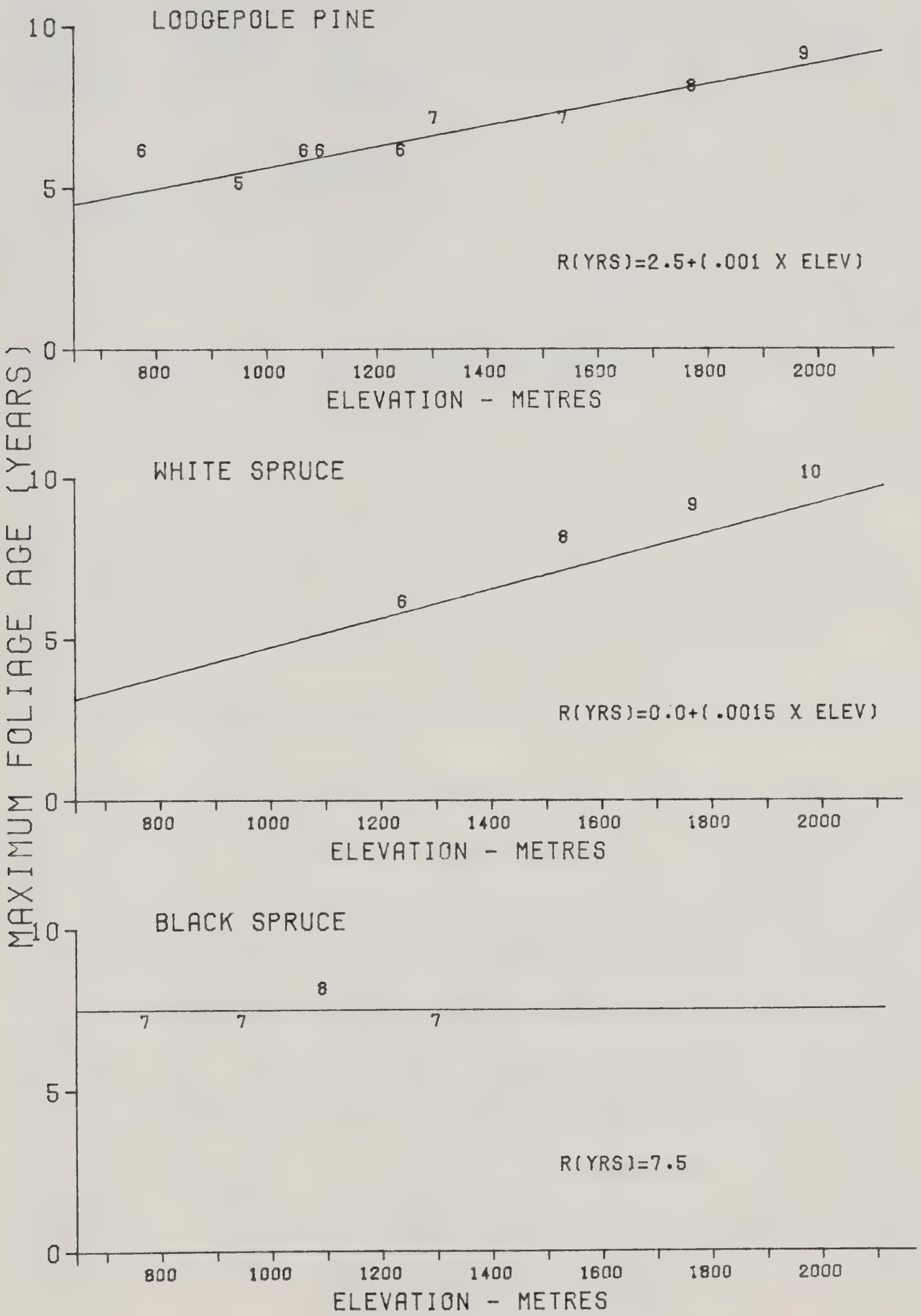
The following is a description of the modelling of these factors based on the relevant data collected before and during the sampling period.

Old foliage correction factor

It has been shown in several studies (Kurbatskii 1972, Chrosciewicz 1976 and Mayo 1976) that the foliage of each of the several ages of needles follow generally parallel foliar moisture content patterns, with foliar moisture content decreasing incrementally with needle age. To account for this in estimating actual overall crown moisture content, it was necessary to consider that the effect will also depend on the period of needle retention within the crown. As found in initial studies, needle retention appeared to increase with elevation. Approximate linear expressions of maximum observed needle retention (R) with elevation were derived (Figure 20). In order to account for needle loss over time, it was assumed that retention with age follows a sigmoid pattern, with increased proportional loss of remaining needles over time. If it is assumed that a likely figure of 2% of the needles of the crowns studied were actually older than the oldest observed, the average needle age would be .258•(R) (taken from the normal curve). The estimated 2% of overlooked needles does not have a large effect on the result, but was necessary in determining the coefficient.

Given the average age of pre-1976 foliage, an estimate of the net effect of older needles could be calculated assuming a constant decrement from each year to the next older. From data presented by van Wagner (1967), Mayo (1976) and Chrosciewicz (1976), estimates of average annual

Figure 20. Observed needle retention for sample locations (with approximated linear expressions for modelling purposes)



moisture decline were derived, as shown in Table 13.

Table 13. Decrement of foliar moisture content decline (dry weight moisture percent) per year (such that for every year increase in needle age, the foliar moisture content will decrease by this increment)

Species	DECREMENT (f.m.c.decline/yr)	
Lodgepole pine	7%	(from jack pine - Chrosciewicz, 1976 Scots Pine - Kurbatskii, 1972 lodgepole Pine - initial studies)
White spruce	7%	(from Chrosciewicz, 1976)
Black spruce	6%	(from Mayo, 1976)

For each species, the correction factor (OLD) would be:

$$OLD = -(.258 \bullet R) \bullet DECREMENT \text{ (in percent)}$$

New foliage correction factor

New foliage contribution to overall crown foliar moisture content would, of course, be dependent on new foliar mass and its moisture content. The moisture content of new foliage has been described in several studies as ranging from about 250 to over 350 percent, depending on the species (van Wagner (1967), Kurbatskii (1972), Mayo (1976) and Chrosciewicz (1976)). For the purpose of simulation, the moisture content is assumed to initiate at 300% at bud-burst, declining with growth to a moisture content closer to that of older foliage by the end of the growing

season. To simulate this behavior, the growth data (Appendix 6), was used to approximate new foliar moisture by starting at a maximum of 300% and moving with growth to normal moisture content when needles reach mature length. The formula to obtain foliar moisture content for new (1977) foliage (Nmc), given the moisture content of the 1976 needles (m), the annual moisture content increment (I), the new foliage length (fn) and the mature foliage length (fm), was:

$$Nmc = 300 - (300-(m+I))\bullet(fn/fm)^2$$

To arrive at the positive factor (NEW) for the model, the new foliar moisture content was multiplied by new foliar mass (Nma - approximated from lineal growth as fn/fm):

$$NEW = (Nma)\bullet(Nmc)$$

The effects of these new and old foliage factors can be seen graphically in examples of overall foliar moisture content shown in Figures 21 through 24.

FIRE OCCURRENCE MODELLING

The estimated overall crown foliar moisture content results were then applied to the crown fire theory model. Through this, isoquant graphs were produced similar to those for foliar moisture content behavior trends.

Ignitibility, in this case, is therefore inversely proportional to the FWI value calculated. As can be seen in Figures 25, 26 and 27, the major variation in ignitibility

Figure 21. Example of simulated foliar moisture content (dry weight moisture percent) for lodgepcle pine of the foothills sampling location at 1770 metres (showing moisture contents of new (1977) foliage, 1-year old (1976) foliage (sampled) and previous foliage (at the given average age) resulting in overall f.m.c.).

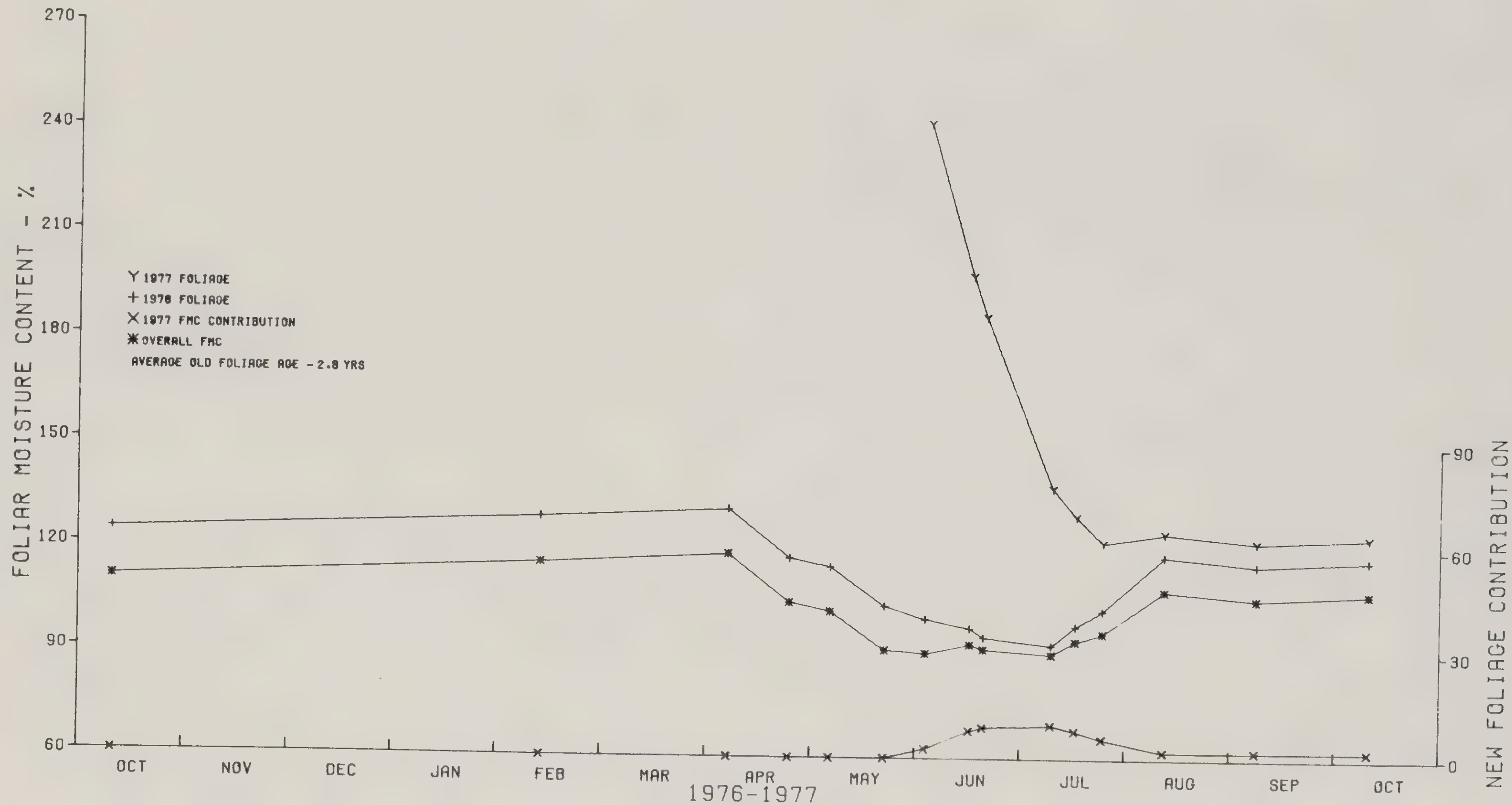


Figure 22. Example of simulated foliar moisture content (dry weight moisture percent) for white-Engelmann spruce of the foothills sampling location at 1980 metres (showing moisture contents of new (1977) foliage, 1-year old (1976) foliage (sampled) and previous foliage (at the given average age) resulting in overall f.m.c.).

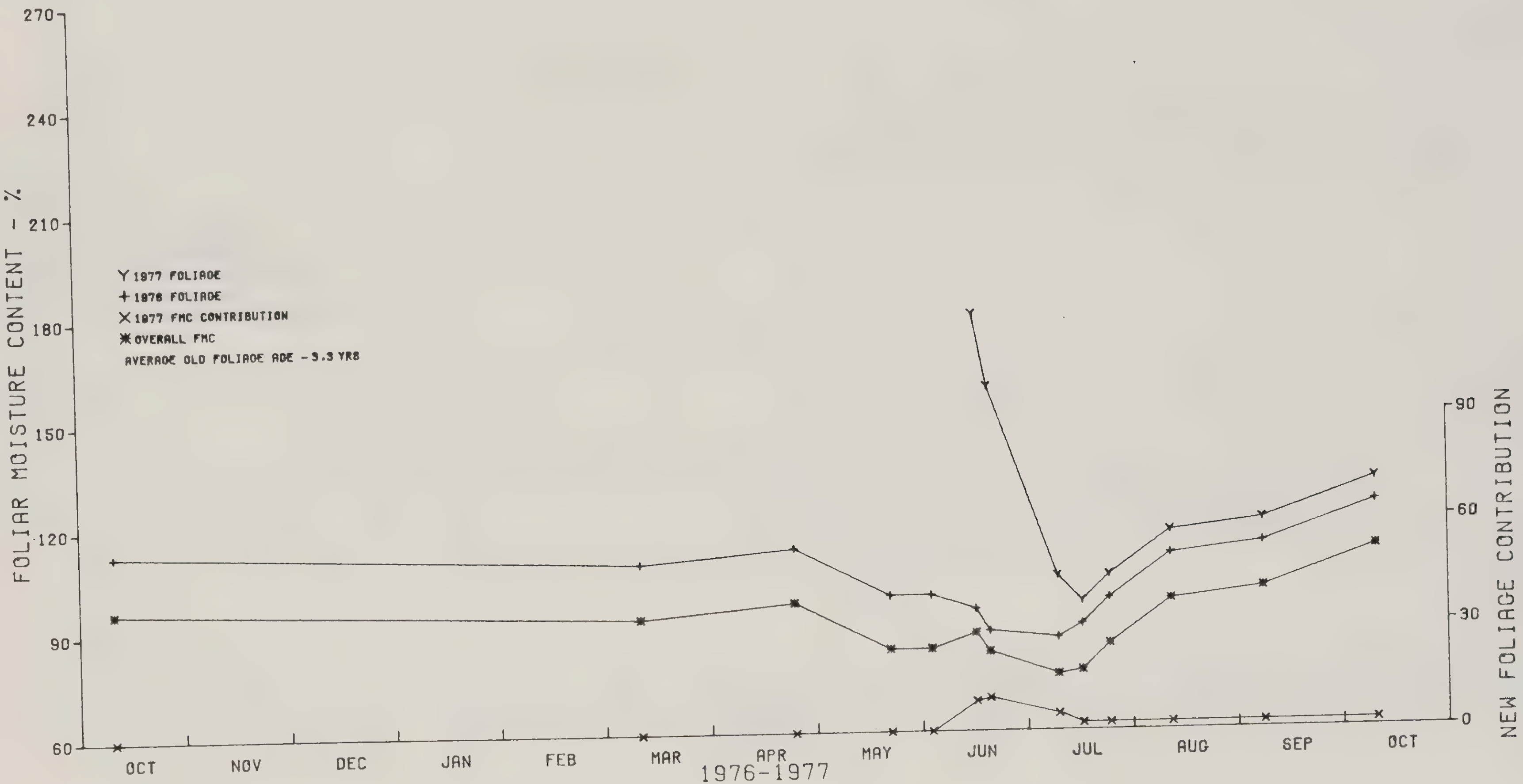


Figure 23. Example of simulated foliar moisture content (dry weight moisture percent) for lodgepole pine of the Swan Hills sampling location at 1070 metres (showing moisture contents of new (1977) foliage, 1-year old (1976) foliage (sampled) and previous foliage (at the given average age) resulting in overall f.m.c.).

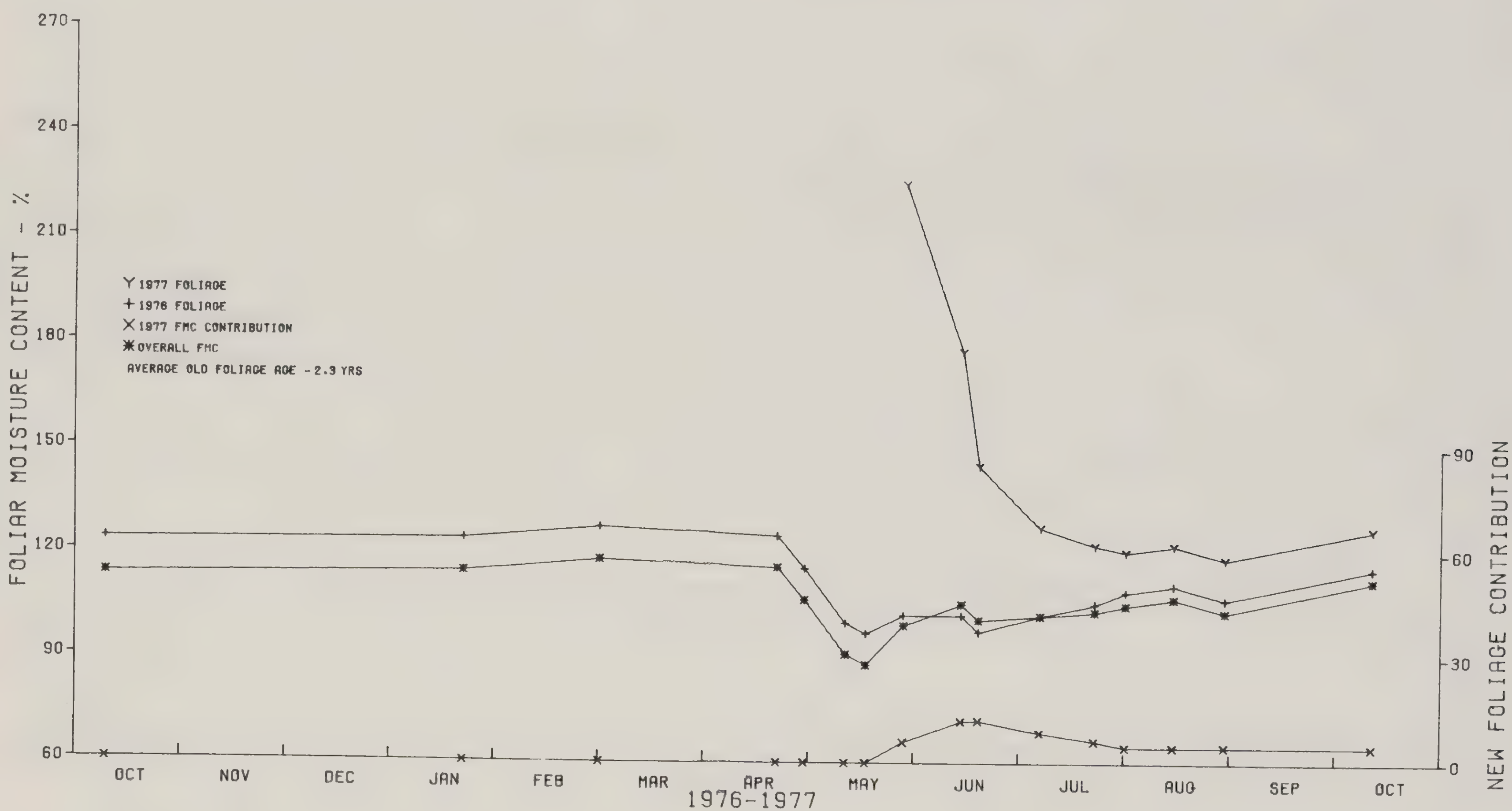


Figure 24. Example of simulated foliar moisture content (dry weight moisture percent) for black spruce of the Swan Hills sampling location at 1070 metres . (showing moisture contents of new (1977) foliage, 1-year old (1976) foliage (sampled) and previous foliage (at the given average age) resulting in overall f.m.c.).

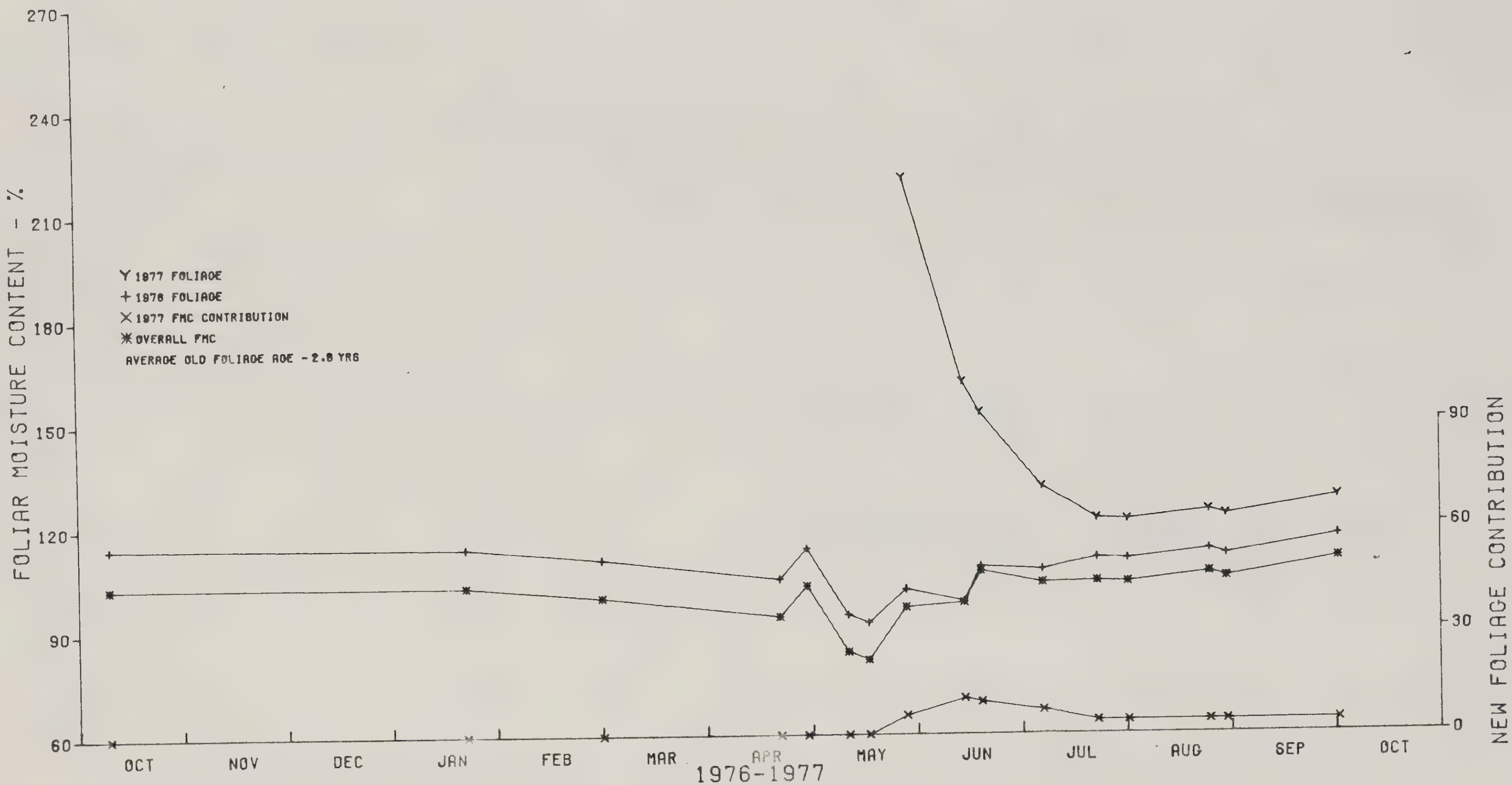


Figure 25. Modelled ignitibility of lodgepole pine crowns at sampled elevations over sampling period (showing isoquants of fire weather index required to initiate crown fires)

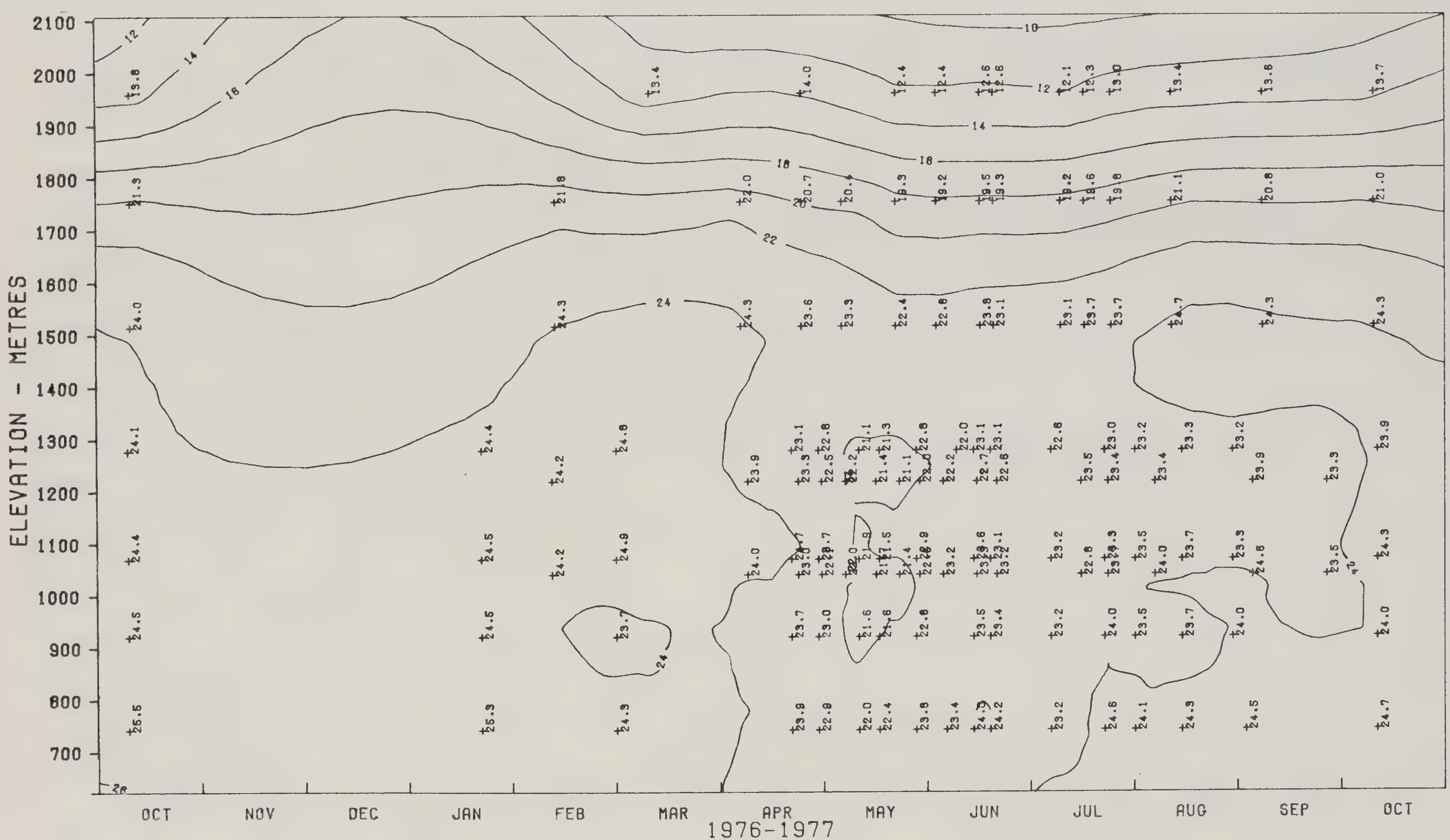


Figure 26. Modelled ignitibility of white-Engelmann spruce crowns at sampled elevations over sampling period (showing isoquants of fire weather index required to initiate crown fires)

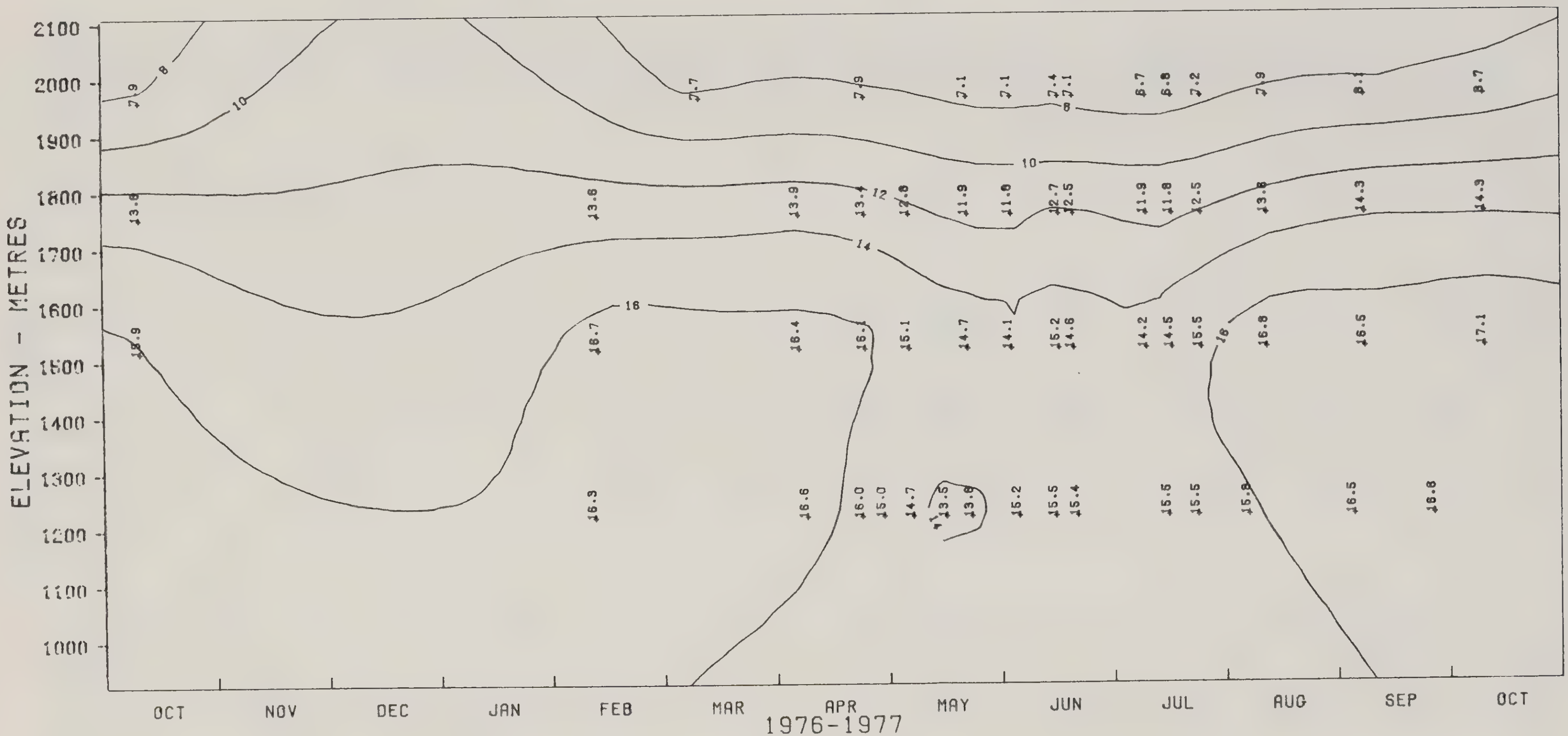
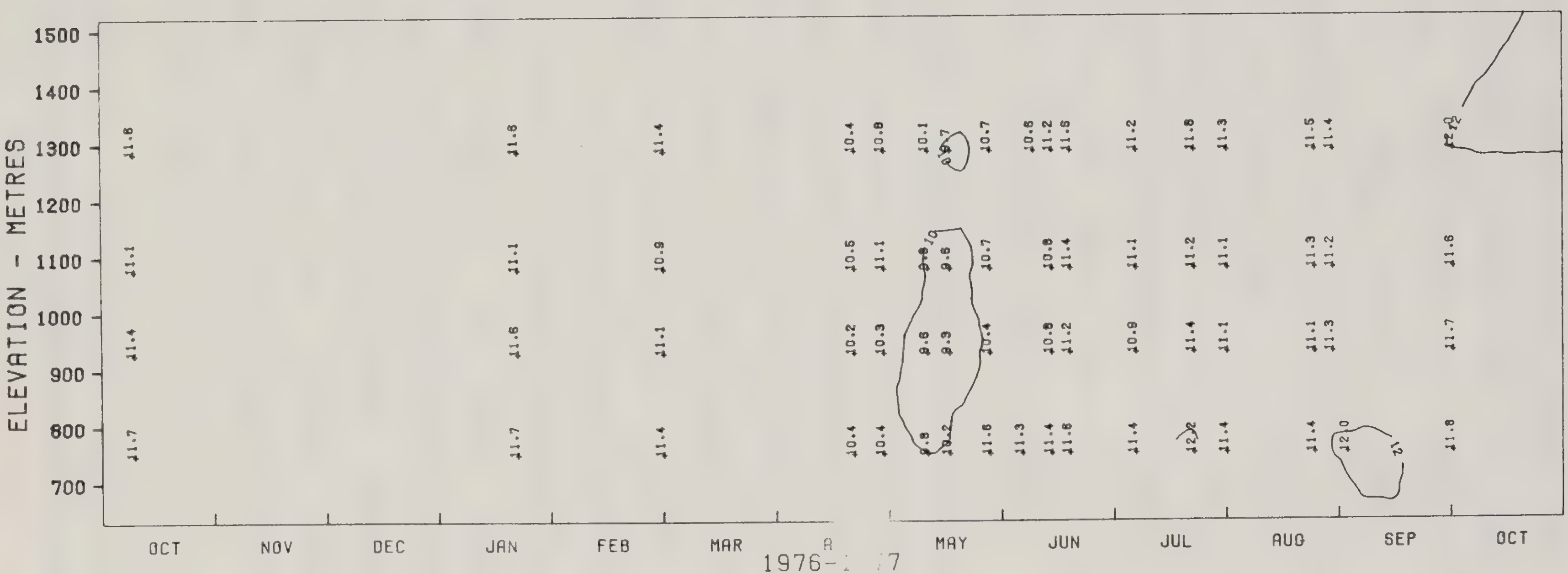


Figure 27. Modelled ignitibility of black spruce crowns at sampled elevations over sampling period (showing isoquants of fire weather index required to initiate crown fires)



of lodgepole pine and white spruce crowns occurs more strongly across the elevational gradient than over time. This is apparently due to the contribution of decreasing crown base height and, to a lesser degree, increasing average needle age with elevation. The variation of FWI isoquant levels over time in all three species demonstrates that the measured fluctuations in foliar moisture content has a relatively small effect on crowning potential. In black spruce, for example, the values range from 12.6 at normal moisture contents to 9.2 during the minimum period.

Figures 28, 29 and 30 show all crown fires documented by the Alberta Forest Service occurring in the study area (the Rocky-Clearwater, Edson, Whitecourt, Grande Prairie and southern Slave Lake Forests) from 1960 to 1976. These fires are plotted by elevation and date on the isoquants of modelled crown ignitibility. Crown fires appear to follow patterns generally similar to the foliar minimum periods (Figure 31). Patterns of yearly variation in crown fire timing are apparent from this analysis, with early crown fire seasons occurring in 1961 and 1971, and late seasons occurring in 1967 and 1974. The average occurrence appears to be 1 to 2 weeks later than the modelled crown ignitibility periods, perhaps a result of the early spring experienced during the sampling period.

Comparison of the modelled ignitibility values to observed FWI values (Table 14) reveals that in all but seven

Figure 28. Crown fire occurrence related to modelled foliar ignitibility for lodgepole pine (fires plotted with modelled ignitibility isoquants with observed fuels, windspeed and actual fire weather index values, where available)

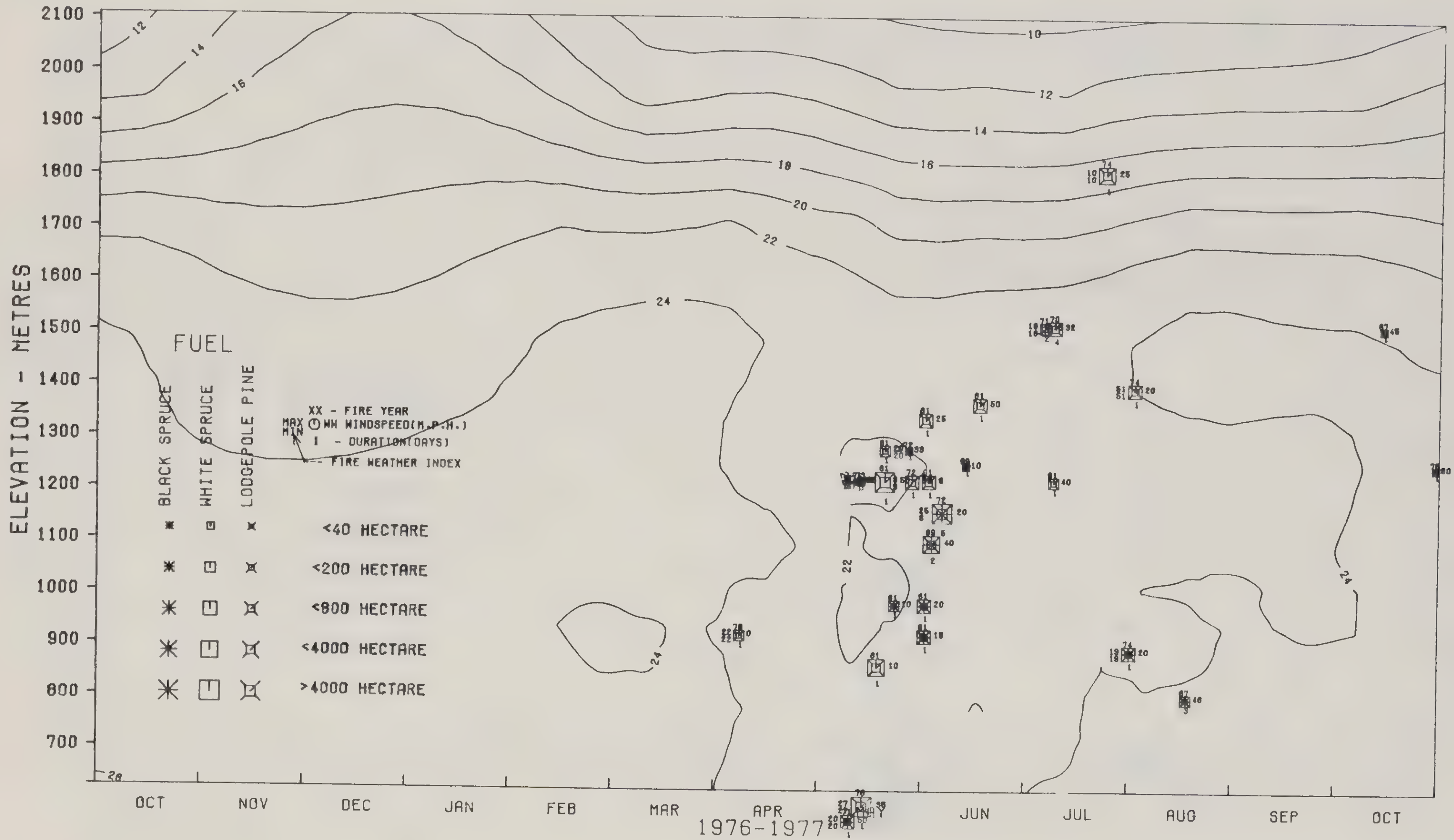


Figure 29. Crown fire occurrence related to modelled foliar ignitibility for white-Engelmann spruce (fires plotted with modelled ignitibility isoquants with observed fuels, windspeed and actual fire weather index values, where available)

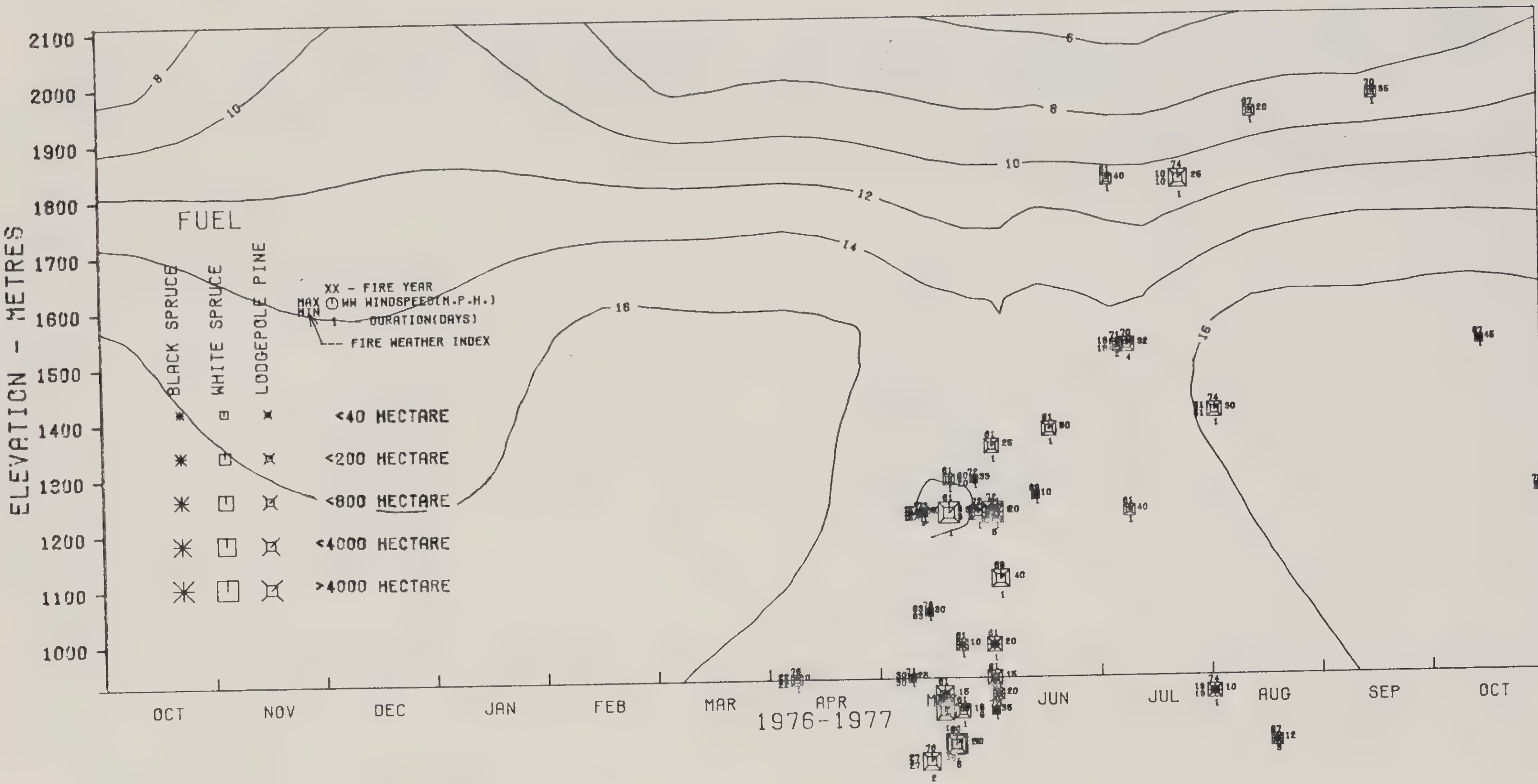


Figure 30. Crown fire occurrence related to modelled foliar ignitibility for black spruce (fires plotted with modelled ignitibility isoquants with observed fuels, windspeed and actual fire weather index values, where available)

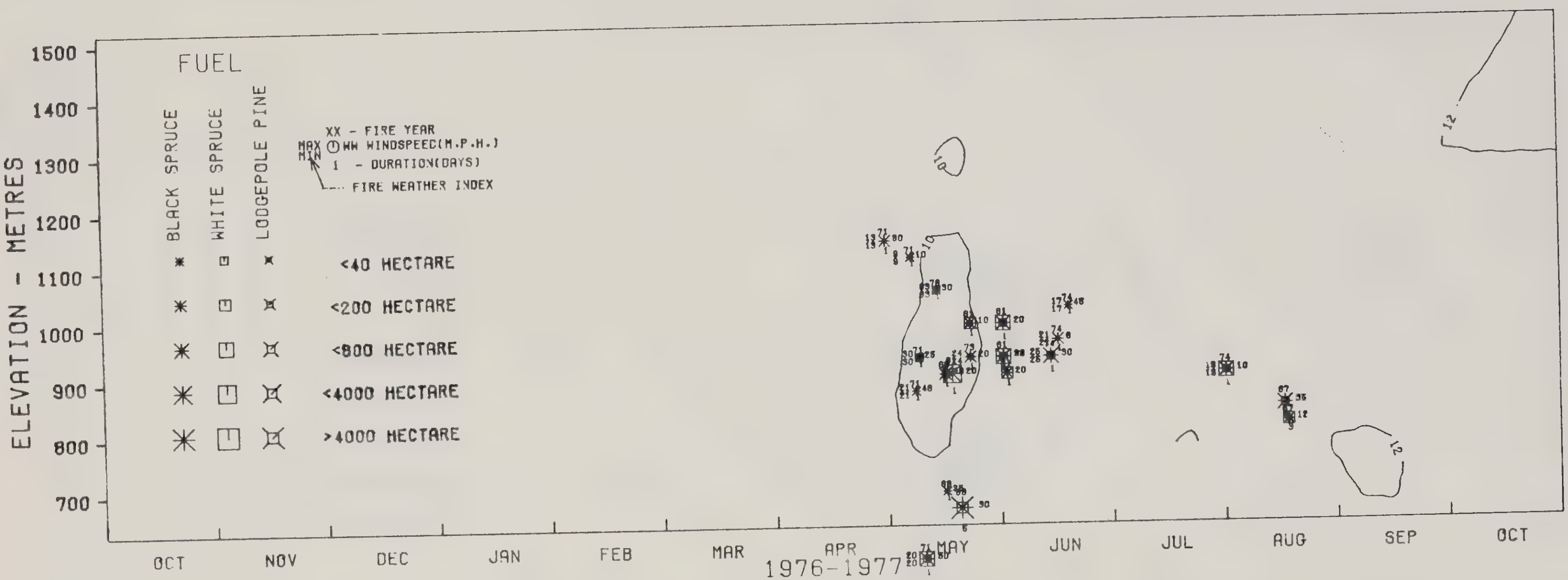


Figure 31. Crown fire occurrence related to averaged foliar moisture content (dry weight moisture percent) of lodgepole pine, white spruce and black spruce showing all fires documented in the study area.

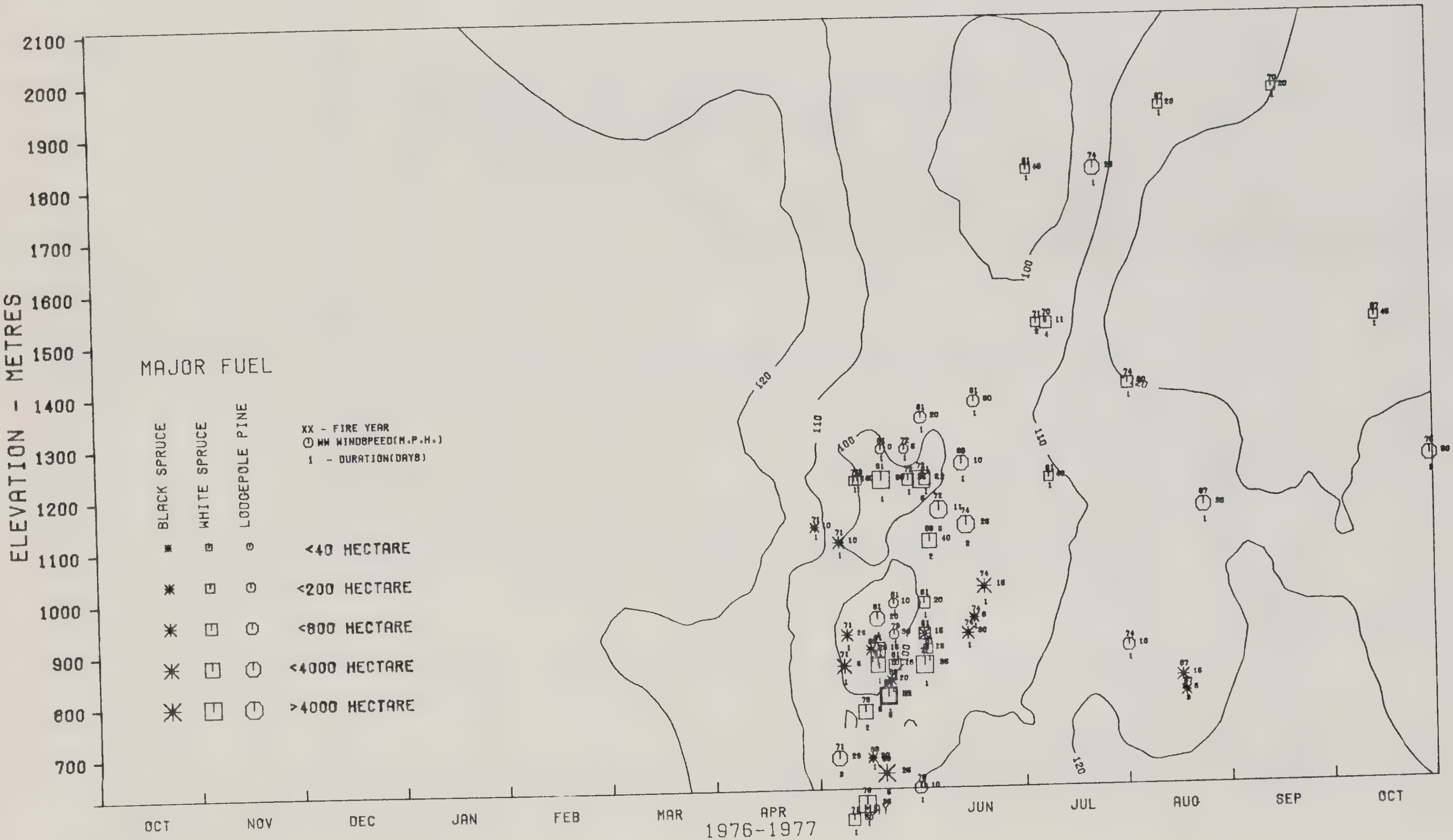


Table 14. Comparison of observed Canadian Fire Weather Index values measured during central Alberta crown fires to modelled FWI crown ignitibility values. (Fire #: Fire District, Year, Number; Fuel: Pl - lodgepole pine, Sw - white-Engelmann spruce, Sb - black spruce)

Fire #	Fuel	Can. Fire Wea. Index Min.	Max.	Model FWI Value Pl	Sw	Sb
E27304	SwPl		27	22	14	
E37408	SwPl		51	24	16	
E47406	Sb		21			11
G27412	PlSwSb		19	23	15	11
G27601	SwPl		22	23	15	
G57104	Pl	26	41	23		
R37104	SwPl		18	21	15	
R37420	PlSw		10	17	11	
R37406	Sb		17			11
R67102	Sb		13			11
R67614	SwSb		63		15	9
R87101	SwPl		11	21	14	
S17107	SwSbPl		20	23	15	11
S17613	SwPl		27	23	15	
S27218	SwSbPl	9	24	22	14	10
S27217	SwPl		9	22	14	
S37101	Sb		9			10
S37105	SbSwPl		30	22	15	10
W17310	PlSb		24	22		11
W17406	SbPl		25	23		11
W17609	Sw		27		15	
W27113	Sb		21			9
W57205	PlSwSb	8	25	22	14	10
W57407	Pl		21	23		

cases the observed FWI value was in fact greater than that predicted necessary for ignition. Only one of the exceptions was more than two values less than expected - fire S27217, burning in lodgepole pine and white spruce at a FWI of 9 whereas the lowest model value (for white spruce) was 14.

From analysis of the data in this simplified model adapted for the purpose, it would appear that crown fires could be expected to have a reasonable chance of starting in average lodgepole pine stands at Canadian Fire Weather Index values of greater than 25 at any time, 22 during the spring period and as low as 16 at high elevations, resulting from the lower crown base height. In white spruce, the values would be 16 for any time, 14 during the spring period and 10 at high elevations, whereas for black spruce, 11 at any time and 9 during the spring period.

This model was intended to provide a framework for describing the observed variation in foliar moisture content in a manner related to crown fire occurrence. According to present crown fire theory, the natural variability of foliar moisture content alone may not be as large a factor under normal climatic conditions as suspected. There is, however, an apparent concentration of crown firesin the study area during the period when foliar moisture content is at a minimum, perhaps a result of concomitant fire behavior factors adding to or accentuating foliar moisture effects as speculated by Kiil, et al. 1977. These factors may relate to

variations in surface fire intensity or crown flammability factors not yet studied.

CHAPTER VII

SUMMARY AND CONCLUSIONS

During the sampling period for this study the spring minimum of foliar moisture content described by van Wagner (1967) was observed in all species at all sampling locations. This implies that the phenomenon would likely have occurred for the observed coniferous species over the entire study area, regardless of elevation or aspect.

Timing of the minimum is affected by elevation in the foothills for lodgepole pine and white spruce. In the Swan Hills, however, the minimum can be expected to occur within a matter of days from extreme low to high elevations, other possible effects being constant. Aspect did not contribute to variation in timing of minimum foliar moisture content.

Testing of other factors related to foliar moisture content behavior in this study was limited to soil temperature. Foliar moisture content appeared to have some relationship to temperatures at the shallow and the deep levels measured. However, the degree of correlation would indicate that soil temperature is not the sole factor. Additionally, it was found that a great deal of variation existed in the foliar moisture content of black spruce. When viewed in light of the evidence presented suggesting strong diurnal variation as well, it is speculated that black spruce is more affected by short-term environmental

conditions. Both of these relationships would merit futher investigation. From the data, it is apparent that phenological development of the foliage is not related to the spring foliar moisture minimum, discovered through samples collected at high elevations.

Efforts to model coniferous crown ignitibility supports evidence that the level of crown fire occurrence is likely affected by several factors, including stand structure, surface fire intensity and foliar moisture content. From analysis of the data in a simplified model of crown ignitibility, it is apparent that the magnitude of effect of foliar moisture on coniferous ignitibility is small compared to the possible effects of stand structure and the intensity of surface fire. Foliar moisture content may not be directly responsible for increased crown fire occurrence, but, it may act in combinatin with these and other indirect factors which singly or together could result in extreme fire behavior.

FURTHER STUDY

To establish a framework for defining the contribution of seasonal fluctuation of coniferous foliage characteristics to fire behavior in Alberta, several stages of investigation are recommended. First, the actual extent of seasonality in flammability of aerial coniferous fuels should be established and correlated to foliar moisture

content and/or other possible factors. If a significant change in flammability is found to exist, the next stage would be to attempt to construct a framework to predict the contribution of coniferous flammability to crown fires. This would involve prediction of flammability elements including, possibly, foliar moisture content. From the evidence presented, several environmental factors appear to be involved in moisture content behavior correlated with soil temperature.

At the operational level, development of a measure of predicting the contribution of aerial fuels to fire behavior would be of considerable value. Constructed as an extension of the Canadian Fire Weather Index, it could describe probabilities and magnitudes of expected increases in intensity, and secondarily predict effects on rate of spread and spotting problems. Such a system would require assessments of coniferous flammability and variation in effects of surface, ladder and aerial fuel structures. Means best suited to applying such information when available would likely be stochastic process or simulation modelling based on both empirical data and actual fire records.

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APPENDIX 1 - SAMPLE DESIGN

DETERMINATION OF THE SOURCE OF VARIANCE

Within crowns

Sampling investigation during the summer of 1976 centered to a large degree on determining the source and extent of foliar moisture content variation. Table 15 shows the observed effect on foliar moisture content of needle position, namely needle crown height or relative height within the crown, and needle crown aspect or the face of the crown from which the needle is extracted (N, E, S or W). The results of a covariate two-way analysis of variance, shown in Table 13 reveal highly significant differences between trees but not between needle crown aspect. Needle crown height did, however, prove to be a highly significant linear covariate, with moisture content decreasing at a rate of 0.625% per metre increase in needle crown height.

Within stands

The following are the results of an F - test for homogeneity of two sources of variation which were encountered in sampling foliage for moisture content (dry weight moisture percent). The first source, labeled Trees, is the variation between the samples of the single trees, obtained from 4 destructively sampled crowns. The second source, labeled Locations, is the variation between samples

Table 15. Effects of needle position on foliar moisture content (dry weight moisture percent) for one year old needles of destructively sampled lodgepole pine crowns

Age/Ht.	Crown A 110/23m	Crown 1[1] 72/15m	Crown 2 76/16m	Crown 3 72/17m	Mean
Foliage height					
Top	116.7%	117.7%	114.3%	114.7%	115.8%
Upper	113.7%	121.1%	115.2%	114.8%	116.2%
Middle	114.0%	123.2%	116.0%	115.9%	117.1%
Low	113.0%	124.8%	114.8%	120.3%	118.2%
V. low	117.2%	125.4%	117.8%	118.6%	119.7%
Sub-crown			118.3%		
Crown-face					
South	115.1%	124.3%	116.2%	115.0%	117.7%
East	115.2%	121.3%	115.4%	117.1%	117.3%
North	115.2%	124.1%	116.2%	115.7%	117.8%
West	112.4%	125.2%	115.8%	117.3%	117.7%
Mean	114.9%	123.4%	115.2%	116.6%	117.5%

[1] Crowns 1, 2 and 3 were sampled August 21, 1976 at 0830, 1230 and 1800 hrs. respectively.

Table 16. Two-way covariate analysis of foliar moisture content (dry weight moisture percent) by needle position in lodgepole pine crowns (with sample trees and crown-face as main effects and relative foliage height as a concommitant variable, all processed simultaneously)

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio	Probability
Covariate					
Height	231.1	1	231.1	21.72	0.0%
Main effects	1422.7	6	237.1	22.29	0.0%
Tree	1412.9	3	471.0	44.26	0.0%
Crown-face	8.9	3	3.0	0.28	84.0%
Interaction					
Tree x Face	106.0	9	11.8	1.11	36.6%
Explained	1759.9	16	110.0	10.34	0.0%
Residual	947.0	89	10.6		
Total	2706.8	105	25.8		

collected from different trees on the seven locations (up to eight trees per location). For Trees, eight values were used from each tree, chosen randomly from the lower middle south-facing portions of the crown as was done with locations.

	Variance	Standard Deviation	Degrees of Freedom
Trees			
1.	15.6	3.96	7
2.	29.1	5.40	7
3.	13.6	3.69	7
4.	19.8	4.45	7
Locations			
1.	34.3	5.68	7
2.	27.9	5.28	7
3.	27.4	5.23	7
4.	18.6	4.31	2
5.	11.5	3.39	6
6.	8.2	2.86	7
7.	6.0	2.44	2

Variance means: Trees - 19.5 Locations - 19.1

F - test: 47.2% probability

From this it may be assumed that the variation of moisture content values is the same on a single tree as it would be over several trees at a given location. Therefore it is likely that the variation found in sampling several

trees on a site would result from variation between the samples of each tree, not from between the trees themselves.

DETERMINATION OF SAMPLE SIZE

In determining the effect of sample size on the resolution of differences between mean values of the sampling sites, the T - test sample size calculation is used (Zalik 1975). The estimate of variance applied in this case is from samples numbered 4 to 7 of the Locations samples, as these more closely represented the actual sampling conditions.

$$r = (2(t+t^*)^2 s^2)/d^2$$

where r = the number of samples required

s^2 = the variance (estimated) of the samples

t = probability of a Type I error
= 1.314 at 90%

t^* = probability of a Type II error
= 2.110 (from T - table) at 95% & 17 degrees of freedom

d = level of measureable difference (resolution)

s = 3.25, giving -

$$r = 2(2.110 + 1.314)^2 \times 10.556/d^2 = 247.5/d^2$$

This gives the r values for varying d as follows:

d	1%	2%	3%	4%	6%	8%	10%	12%	15%
r	248	62	28	16	7	4	3	2	2

In order to be able to statistically resolve the

differences of fcliar moisture content at a rate of change of 7 to 10% per week (anticipated sampling rate) observed in other studies, a sample size of 6 was chosen.

APPENDIX 2 - SAMPLING LOCATION DESCRIPTIONS

The following 21 pages represent site descriptions of all of the sampling locations used during the period from October, 1976 to October, 1977. For locations where more than one species was present, there is a description for each of the species. Locations and elevations (mean sea level) were determined from contour maps of the areas. Photographs were taken when the sites were being established during 1976. The surface vegetation was estimated as percent cover. Soil texture represents the upper horizon only.

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
2.4P1

AREA:
Swan Hills

ELEVATION:
730 m (2400')

SPECIES:
Lodgepole pine

STAND DENSITY:

BASAL AREA:
10.3 m^2/ha
(45 ft^2/acre)
CROWN CLOSURE:
45%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	55	18	17	5
2.	51	19	18	6
3.	52	16	16	5
4.	55	18	17	5
5.	57	16	16	4
6.	57	17	16	6
	55	17	17	5.2

SITE:

SLOPE: 0%

DRAINAGE: Mod-well SOIL TEXTURE: Sandy loam

VEGETATION:

OVERSTORY: Lodgepole pine, Black spruce

UNDERSTORY: Labrador tea (10%)

SURFACE: Lichens (40%), Mosses (30%), Herbs (20%)

LOCATION:

LATITUDE: 54°07'30" LONGITUDE: 115°38'48"

TIEPOINT: 1.3 km (.8 mi) east of Whitecourt limits (Hwy 43)

RELATIVE: 40 m (2 chains) north of road

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
2.4Sb

AREA:
Swan Hills

ELEVATION:
730 m (2400')

SPECIES:
Black spruce

STAND DENSITY:

BASAL AREA:
10.3 m^2/ha
(45 $ft^2/acre$)
CROWN CLOSURE:
40%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	58	23	15	<1
2.	56	17	14	<1
3.	52	15	12	<1
4.	59	22	16	1
5.	53	20	16	<1
6.	58	22	17	1
	56	17	15	1

SITE:

SLOPE: 0%

DRAINAGE: Mod-well SOIL TEXTURE: Sandy loam

VEGETATION:

OVERSTORY: Lodgepole pine, Black spruce

UNDERSTORY: Labrador tea (10%)

SURFACE: Lichens (40%), Mosses (30%), Herbs (20%)

LOCATION:

LATITUDE: 54°07'30" LONGITUDE: 115°38'48"

TIEPOINT: 1.3 km (.8 mi) east of Whitecourt limits (Hwy 43)

RELATIVE: 40 m (2 chains) north of road

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
3.0P1

AREA:
Swan Hills

ELEVATION:
910 m (3000')

SPECIES:
Lodgepole pine

STAND DENSITY:

BASAL AREA:
9.2 m^2/ha
(40 ft^2/acre)
CROWN CLOSURE:
35%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	56	20	18	2
2.	59	18	20	3
3.	61	19	19	3
4.	57	18	20	4
5.	53	19	19	2
6.	49	20	17	2
	56	19	19	2.7

SITE:

SLOPE:	1%	ASPECT:	South
DRAINAGE:	Mod-well	SOIL TEXTURE:	Loam

VEGETATION:

OVERSTORY: Lodgepole pine, Black spruce

UNDERSTORY: Labrador tea (30%)

SURFACE: Mosses (40%), Lichens (10%), Herbs & grasses (20%), Litter (20%)

LOCATION:

LATITUDE: 54°36'24" LONGITUDE: 115°23'00"

TIEPOINT: 11.4 km (7.1 mi) south of Swan Hills (Hwy 932)

RELATIVE: 70 m (3.5 chains) west of road

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
3.0Sb

AREA:
Swan Hills

ELEVATION:
910 m (3000')

SPECIES:
Black spruce

STAND DENSITY:

BASAL AREA:
9.2 m^2/ha
(40 ft^2/acre)
CROWN CLOSURE:
35%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	62	13	8	1
2.	54	14	10	2
3.	59	18	12	<1
4.	58	19	13	1
5.	60	16	14	1
6.	58	12	12	1
	59	15	12	1.1

SITE:

SLOPE: 1% ASPECT: South

DRAINAGE: Mod-well SOIL TEXTURE: Loam

VEGETATION:

OVERSTORY: Lodgepole pine, Black spruce

UNDERSTORY: Labrador tea (30%)

SURFACE: Mosses (40%), Lichens (10%), Herbs & grasses (20%), Litter (20%)

LOCATION:

LATITUDE: 54°36'24" LONGITUDE: 115°23'00"

TIEPOINT: 11.4 km (7.1 mi) south of Swan Hills (Hwy 932)

RELATIVE: 70 m (3.5 chains) west from road

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
3.5Pl

AREA:
Swan Hills

ELEVATION:
1070 m (3500')

SPECIES:
Lodgepole pine

STAND DENSITY:

BASAL AREA:
11.5 m^2/ha
(50 ft^2/acre)
CROWN CLOSURE:
50%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	63	21	19	4
2.	60	18	18	5
3.	61	19	17	4
4.	64	20	20	3
5.	62	19	18	5
6.	59	19	17	4
	62	19	18	4.2

SITE:

SLOPE: 5% ASPECT: West

DRAINAGE: Mod-well SOIL TEXTURE: Loam

VEGETATION:

OVERSTORY: Lodgepole pine, Black spruce

UNDERSTORY: Labrador tea (25%)

SURFACE: Mosses (40%), Lichens (25%), Bearberry & grasses (10%)

LOCATION:

LATITUDE: 54°42'24" LONGITUDE: 115°24'36"

TIEPOINT: 1.6 km (1.0 mi) south of Swan Hills (Hwy 932)

RELATIVE: 40 m (12 chain) east of road

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
3.5Sb

AREA:
Swan Hills

ELEVATION:
1070 m (3500')

SPECIES:
Black spruce

STAND DENSITY:

BASAL AREA:
11.5 m^2/ha
(50 ft^2/acre)
CROWN CLOSURE:
50%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	48	15	8	2
2.	60	14	8	2
3.	51	17	7	1
4.	51	18	9	<1
5.	52	17	10	<1
6.	50	15	9	≤1
	52	16	9	1.2

SITE:

SLOPE: 2% ASPECT: North

DRAINAGE: Mod-well SOIL TEXTURE: Loam

VEGETATION:

OVERSTORY: Lodgepole pine, Black spruce

UNDERSTORY: Labrador tea (40%)

SURFACE: Mosses (45%), Lichens (20%), Bearberry & grasses (10%)

LOCATION:

LATITUDE: 54°42'24" LONGITUDE: 115°24'36"

TIEPOINT: 1.6 km (1.0 mi) south of Swan Hills (Hwy 932)

RELATIVE: 40 m (12 chain) east of road

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
4.2P1

AREA:
Swan Hills

ELEVATION:
1280 m (4200')

SPECIES:
Lodgepole pine

STAND DENSITY:

BASAL AREA:
10.3 m^2/ha
(45 ft^2/acre)
CROWN CLOSURE:
40%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	73	22	20	6
2.	66	18	14	4
3.	71	19	18	4
4.	69	20	17	4
5.	68	21	19	5
6.	76	22	21	5
	71	20	18	4.7

SITE:

SLOPE: 2% ASPECT: South

DRAINAGE: Moderate SOIL TEXTURE: Silt-loam

VEGETATION:

OVERSTORY: Lodgepole pine, Black spruce

UNDERSTORY: Labrador tea (20%)

SURFACE: Mosses (60%), Lichens (30%), Bearberry (10%)

LOCATION:

LATITUDE: 54°50'36" LONGITUDE: 115°20'42"

TIEPOINT: 4.8 km (3.0 mi) north of Swan Hills (Hwy 932)

RELATIVE: 40 m (2 chains) south of road

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
4.2Sb

AREA:
Swan Hills

ELEVATION:
1280 m (4200')

SPECIES:
Black spruce

STAND DENSITY:

BASAL AREA:
10.3 m^2/ha
(45 ft^2/acre)
CROWN CLOSURE:
40%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	67	23	13	2
2.	54	19	10	2
3.	63	16	9	1
4.	66	24	14	2
5.	58	20	8	<1
6.	69	24	12	<1
	63	21	11	1.5

SITE:

SLOPE: 2% ASPECT: South

DRAINAGE: Moderate SOIL TEXTURE: Silt-loam

VEGETATION:

OVERSTORY: Lodgepole pine, Black spruce

UNDERSTORY: Labrador tea (20%)

SURFACE: Mosses (60%), Lichens (30%), Bearberry (10%)

LOCATION:

LATITUDE: 54°50'36" LONGITUDE: 115°20'42"

TIEPOINT: 4.8 km (3.0 mi) north of Swan Hills (Hwy 932)

RELATIVE: 40 m (2 chains) south of road

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
3PL

AREA:
Foothills

ELEVATION:
1040 m (3400')

SPECIES:
Lodgepole pine

STAND DENSITY:

BASAL AREA:
13.8 m^2/ha
(60 ft^2/acre)
CROWN CLOSURE:
50%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	72	22	20	6
2.	66	19	19	6
3.	70	18	18	5
4.	69	20	19	6
5.	72	21	18	5
6.	73	22	19	6
	70	20	19	5.7

SITE:

SLOPE: 0%

DRAINAGE: Mod-well SOIL TEXTURE: Sandy loam

VEGETATION:

OVERSTORY: Lodgepole pine

UNDERSTORY: Labrador tea (20%)

SURFACE: Mosses (35%), Lichens (30%), Herbs (10%)

LOCATION:

LATITUDE: 53°16'12" LONGITUDE: 116°57'00"

TIEPOINT: 13.1 km (8.2 mi) north of Robb Junction (Hwy 47)

RELATIVE: 60 m (3 chains) east of road

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
4P1

AREA:
Foothills

ELEVATION:
1220 m (4000')

SPECIES:
Lodgepole pine

STAND DENSITY:

BASAL AREA:
11.5 m²/ha
(50 ft²/acre)
CROWN CLOSURE:
40%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	70	23	20	2
2.	66	22	22	6
3.	74	20	23	7
4.	73	21	23	4
5.	69	21	22	4
6.	69	21	21	5
	70	21	22	4.7

SITE:

SLOPE: 2% ASPECT: South-west

DRAINAGE: Well SOIL TEXTURE: Sand

VEGETATION:

OVERSTORY: Lodgepole pine

UNDERSTORY: Black spruce (5%), Shrub birch (20%)

SURFACE: Lichens (40%), Grasses (50%), some Herbs

LOCATION:

LATITUDE: 53°09'53" LONGITUDE: 117°01'06"

TIEPOINT: 1.4 km (.9 mi) west of Lovett Junction (Hwy 47)

RELATIVE: 60 m (3 chains) south of road

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
4Sw

AREA:
Foothills

ELEVATION:
1220 m (4000')

SPECIES:
White spruce

STAND DENSITY:

BASAL AREA:
9.2 m^2/ha
(40 ft^2/acre)
CROWN CLOSURE:
40%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	50	20	20	4
2.	48	19	18	4
3.	51	20	19	3
4.	46	21	15	1
5.	49	18	16	4
6.	46	19	17	3
	48	20	18	3.2

SITE:

SLOPE: 0%

DRAINAGE: Mod-well SOIL TEXTURE: Sandy

VEGETATION:

OVERSTORY: White spruce, Black spruce, Lodgepole pine

UNDERSTORY: Salix spp. (15%)

SURFACE: Mosses (30%), Grasses (45%)

LOCATION:

LATITUDE: 53°09'54" LONGITUDE: 117°03'00"

TIEPOINT: 3.5 km (2.2 mi) west of Lovett Junction (Hwy 47)

RELATIVE: 80 m (4 chains) south of road

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
5P1

AREA:
Foothills

ELEVATION:
1520 m (1520 m (5000')')

SPECIES:
Lodgepole pine

STAND DENSITY:

BASAL AREA:
12.6 m^2/ha
(55 ft^2/acre)
CROWN CLOSURE:
55%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	63	23	20	2
2.	62	22	20	2
3.	65	21	23	2
4.	59	22	21	3
5.	63	21	23	6
6.	71	21	25	7
	64	22	22	4.3

SITE:

SLOPE: 0%

DRAINAGE: Well SOIL TEXTURE: Coarse

VEGETATION:

OVERSTORY: Lodgepole pine

UNDERSTORY: White spruce (5%)

SURFACE: Mosses (35%), Grasses (30%), Herbs (15%)

LOCATION:

LATITUDE: 52°52'48" LONGITUDE: 116°53'36"

TIEPOINT: .3 km (.2 mi) south-east of Cardinal Riv. Br.

RELATIVE: 40 m (2 chains) west of road

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
5Sw

AREA:
Foothills

ELEVATION:
1520 m (5000')

SPECIES:
White spruce

STAND DENSITY:

BASAL AREA:
14.9 m^2/ha
(65 ft^2/acre)
CROWN CLOSURE:
45%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	57	18	16	2
2.	59	16	15	1
3.	59	17	17	2
4.	55	16	17	2
5.	61	18	18	3
6.	66	18	20	3
	60	17	17	2.2

SITE:

SLOPE: 0%

DRAINAGE: Mod-well SOIL TEXTURE: Silty-loam/coarse

VEGETATION:

OVERSTORY: Overmature white spruce

UNDERSTORY: White spruce regen.

SURFACE: Mosses (45%), Grasses (10%), Lichens (30%)

LOCATION:

LATITUDE: 52°52'24" LONGITUDE: 116°56'18"

TIEPOINT: .5 km (.3 mi) east of Grave Flats Cabin

RELATIVE: 30 m (1.5 chains) south of road

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
6P1

AREA:
Foothills

ELEVATION:
1770 m (5800')

SPECIES:
Lodgepole pine

STAND DENSITY:

BASAL AREA:
10.3 m^2/ha
(45 ft^2/acre)
CROWN CLOSURE:
35%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	69	20	18	6
2.	72	21	17	5
3.	66	16	16	2
4.	63	17	17	2
5.	69	16	13	2
6.	71	20	19	5
	68	18	17	3.7

SITE:

SLOPE: 0%

DRAINAGE: Rapidly

SOIL TEXTURE: Loam/coarse

VEGETATION:

OVERSTORY: Lodgepole pine, White (?) spruce

UNDERSTORY: White (?) spruce regen. (5%)

SURFACE: Grasses (30%), Mosses (40%)

LOCATION:

LATITUDE: 52°52'42"

LONGITUDE: 116°58'36"

TIEPOINT: 2.9 km (1.8 mi) up Grave Flats Lookout road

RELATIVE: On bench, 40 m (2 chains) north (up hill)

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
6Sw

AREA:
Foothills

ELEVATION:
1770 m (5800')

SPECIES:
White spruce (?)

STAND DENSITY:

BASAL AREA:
10.3 m^2/ha
(45 ft^2/acre)
CROWN CLOSURE:
35%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	54	14	12	2
2.	58	13	14	1
3.	60	15	13	4
4.	59	14	12	1
5.	62	16	16	2
6.	55	16	14	2
	58	15	14	2.0

SITE:

SLOPE: 0%

DRAINAGE: Rapidly SOIL TEXTURE: Loam/coarse

VEGETATION:

OVERSTORY: Lodgepole pine, White(?) spruce

UNDERSTORY: White(?) spruce regen. (5%)

SURFACE: Grasses(30%), Mosses(40%)

LOCATION:

LATITUDE: 52°52'42" LONGITUDE: 116°58'36"

TIEPOINT: 2.9 km (1.8 mi) up Grave Flats Lookout road

RELATIVE: On bench, 40 m (2 chains) north (up hill)

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
6.5P1

AREA:
Foothills

ELEVATION:
1980 m (6500')

SPECIES:
Lodgepole pine

STAND DENSITY:

BASAL AREA:
6.9 m^2/ha
(30 ft^2/acre)
CROWN CLOSURE:
20%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	53	21	6	2
2.	51	20	5	2
3.	48	20	6	1
4.	50	18	5	2
5.	50	20	5	2
6.	49	18	5	1
	50	19	5	1.7

SITE:

SLOPE: 5% ASPECT: West

DRAINAGE: Rapidly SOIL TEXTURE: Very coarse

VEGETATION:

OVERSTORY: Lodgepole pine, Engelmann spruce

UNDERSTORY: None

SURFACE: Bare ground (40%), Litter & Grasses (30%)

LOCATION:

LATITUDE: 52°53'48" LONGITUDE: 117°00'00"

TIEPOINT: .6 km (.4 mi) northwest of Grave Flats Lookout

RELATIVE: 200 m (10 chains) off road - north along ridge

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
6.5Se

AREA:
Foothills

ELEVATION:
1980 m (6500')

SPECIES:
Englemann spruce

STAND DENSITY:

BASAL AREA:
8.0 m^2/ha
(35 ft^2/acre)
CROWN CLOSURE:
25%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	61	14	5	<1
2.	58	16	4	1
3.	57	14	5	<1
4.	60	14	4	<1
5.	61	13	4	1
6.	57	15	5	1
	59	14	5	1

SITE:

SLOPE: 3% ASPECT: West

DRAINAGE: Rapidly SOIL TEXTURE: Very coarse

VEGETATION:

OVERSTORY: Engelmann spruce, Lodgepole pine

UNDERSTORY: None

SURFACE: Bare ground (40%), Litter & grasses (30%)

LOCATION:

LATITUDE: 52°53'48" LONGITUDE: 117°00'00"

TIEPOINT: .6 km (.4 mi) northwest of Grave Flats Lookout

RELATIVE: 200 m (10 chains) off road - north along ridge

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
SF

AREA:
Foothills

ELEVATION:
1280 m (4200')

SPECIES:
Lodgepole pine

STAND DENSITY:

BASAL AREA:
9.2 m²/ha
(40 ft²/acre)
CROWN CLOSURE:
30%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	61	28	17	2
2.	71	25	19	5
3.	69	24	19	4
4.	62	23	17	5
5.	67	21	17	5
6.	72	24	17	4
	67	24	18	5.2

SITE:

SLOPE: 34%   ASPECT: South

DRAINAGE: Rapidly   SOIL TEXTURE: Coarse

VEGETATION:

OVERSTORY: Lodgepole pine

UNDERSTORY: None

SURFACE: Litter(40%), Herbs(15%), Grasses(5%), Mosses(5%)

LOCATION:

LATITUDE: 53°10'24"   LONGITUDE: 117°00'18"

TIEPOINT: 4.8 km (3.0 mi) south from Robb Junction (Hwy 47)

RELATIVE: 900 m (30 chains) south (up hill to summit)

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
EF

AREA:
Foothills

ELEVATION:
1280 m (4200')

SPECIES:
Lodgepole pine

STAND DENSITY:

BASAL AREA:
9.2 m^2/ha
(40 ft^2/acre)
CROWN CLOSURE:
35%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	73	27	19	10
2.	70	21	18	8
3.	68	23	18	8
4.	72	26	17	3
5.	66	24	19	9
6.	65	25	19	8
	69	24	18	7.6

SITE:

SLOPE: 37% ASPECT: East

DRAINAGE: Well SOIL TEXTURE: Sandy/coarse;

VEGETATION:

OVERSTORY: Lodgepole pine

UNDERSTORY: Alder (30%)

SURFACE: Mosses (30%), Grasses (10%), Lichens & herbs (20%)

LOCATION:

LATITUDE: 53°10'24" LONGITUDE: 117°00'18"

TIEPOINT: 4.8 km (3.0 mi) south from Robb Junction (Hwy 47)

RELATIVE: 900 m (30 chains) north (up hill to summit)

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
WF

AREA:
Foothills

ELEVATION:
1280 m (4200')

SPECIES:
Lodgepole pine

STAND DENSITY:

BASAL AREA:
8.0 m^2/ha
(35 ft^2/acre)
CROWN CLOSURE:
30%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	61	27	17	2
2.	64	23	18	6
3.	66	25	18	4
4.	67	26	17	2
5.	69	24	18	5
6.	71	22	19	6
	66	25	18	4.2

SITE:

SLOPE: 32% ASPECT: West

DRAINAGE: Rapidly SOIL TEXTURE: Coarse

VEGETATION:

OVERSTORY: Lodgepole pine

UNDERSTORY: Alder (10%)

SURFACE: Lichens (30%), Mosses (25%), Grasses & herbs (10%), Bare ground (10%)

LOCATION:

LATITUDE: 53°10'24" LONGITUDE: 117°00'18"

TIEPOINT: 4.8 km (3.0 mi) south from Robb Junction (Hwy 47)

RELATIVE: 900 m (30 chains) north (up hill to summit)

SAMPLING LOCATION DESCRIPTION

SAMPLING LOC.:
NF

AREA:
Foothills

ELEVATION:
1280 m (4200')

SPECIES:
Lodgepole pine

STAND DENSITY:

BASAL AREA:
9.2 m^2/ha
(40 ft^2/acre)
CROWN CLOSURE:
35%

SAMPLING TREES:

	AGE yrs	DBH cm	HGT m	BASE m
1.	63	27	19	4
2.	72	24	18	3
3.	66	25	19	5
4.	68	26	17	3
5.	69	25	19	4
6.	62	26	20	8
	67	25	19	4.5

SITE:

SLOPE: 39%   ASPECT: North

DRAINAGE: Well   SOIL TEXTURE: Sandy loam

VEGETATION:

OVERSTORY: Lodgepole pine

UNDERSTORY: Alder(5%)

SURFACE: Moss(100%)

LOCATION:

LATITUDE: 53°10'24"   LONGITUDE: 117°00'18"

TIEPOINT: 4.8 km (3.0 mi) south from Robb Junction (Hwy 47)

RELATIVE: 900 m (30 chains) north (up hill to summit)

APPENDIX 3 - GROUP MEAN COMPARISON SUMMARY

The following is a comparative analysis of the group data obtained during the sampling period from October, 1976 to October, 1977. There are two pages each for the species included on both areas and for the aspect locations. The means are printed with the collection date by collection period (rows), and by elevation or aspect (columns). Tukey's multiple comparison test has been applied, whereby means are compared based on the pooled variance, and arranged in groups whose means are statistically comparable. The groups are subsequently labeled with common alphabetic characters (with A applying to the lowest mean value group).

To further explain the format of the data layout, the following is an example:

```
                                    XXXXX ------ The elevation or aspect

                                  ┌────────┐
Mean foliar moist. content -+ 000.0%|XXX - Tukey's m.c.t.: row
Collection date ------------+ MONaa |
                                  └────────┘
                                   XXXX ------- Tukey's m.c.t.: column
```

TUKEY'S MULTIPLE COMPARISON TEST - FOOTHILLS LODGEPOLE PINE

3400 FEET	4000 FEET	5000 FEET	5800 FEET	6500 FEET
		125.5% A OCT10 CD	128.3% A OCT10 CDE	126.8% A OCT10 E
124.2% A FEB12 G	125.2% A FEB12 G	127.8% A FEB13 D	133.1% A FEB13 DE	
122.5% AB APR11 FG	122.4% AB APR11 FG	128.3% BC APR09 D	135.8% C APR09 E	120.3% A MAR13 E
112.2% A APR26 BCDE	116.7% A APR26 DEFG	121.3% AB APR27 BCD	121.0% AB APR27 C	127.8% B APR27 E
104.5% MAY03 ABCD	108.7% MAY03 BCDE			
103.1% A MAY10 ABCD	105.8% A MAY10 BCD	118.2% B MAY09 ABCD	118.4% B MAY09 C	
100.9% MAY19 AB	99.1% MAY19 ABC			
95.6% AB MAY26 A	94.2% A MAY26 A	109.6% B MAY25 AB	106.5% B MAY25 B	106.2% B MAY25 CD
101.7% JUN01 ABC	99.3% JUN01 ABC			

FOOTHILLS LODGEPOLE PINE - CONTINUED

3400 FEET	4000 FEET	5000 FEET	5800 FEET	6500 FEET
103.8% AB JUN08 ABCD	98.2% A JUN08 AB	110.0% B JUN07 AB	102.6% AB JUN07 AB	103.5% AB JUN07 BC
101.3% A JUN18 AB	100.4% A JUN18 ABC	113.0% B JUN19 ABC	99.9% A JUN19 ABC	101.4% A ABC
103.6% AB JUN24 ABC	98.3% AB JUN24 AB	105.9% B JUN23 A	97.2% A JUN23 AB	100.4% AB JUN23 ABC
		105.7% B JUL13 A	94.8% A JUL13 A	91.0% A JUL13 A
108.2% BC JUL19 BCDE	107.7% BC JUL19 BCDE	113.0% C JUL20 ABC	100.7% AB JUL20 AB	94.3% A JUL20 AB
115.6% B JUL27 EFG	109.9% AB JUL27 CDE	115.6% B JUL28 ABCD	105.5% A JUL28 AB	107.6% AB JUL28 CD
118.9% AB AUG10 FG	113.8% A AUG10 DEFG	129.1% B AUG15 D	122.3% AB AUG15 CD	117.2% AB AUG15 DE
123.9% A SEP08 G	118.7% A SEP08 EFG	124.9% A SEP11 CD	119.6% A SEP11 C	120.0% A SEP11 E
113.3% A SEP30 DEFG	113.0% A SEP30 DEF	124.6% B OCT14 CD	121.2% AB OCT14 C	121.6% AB OCT14 E

TUKEY'S MULTIPLE COMPARISON TEST - FOOTHILLS WHITE SPRUCE

4000 FEET	5000 FEET	5800 FEET	6500 FEET
	124.8% A OCT10 DEF	123.1% A OCT10 DE	116.5% A OCT10 EF
126.4% A FEB12 GHI	134.6% A FEB13 F	123.6% A FEB13 DE	
130.9% B APR11 I	129.8% B APR09 F	126.6% B APR09 DE	112.1% A MAR13 DE
121.7% AB APR26 EFGHI	126.2% B APR27 EF	120.4% AB APR27 CDE	116.3% A APR27 D
108.9% MAY03 BCDEF			
105.4% A MAY10 BCD	113.8% A MAY09 CD	111.8% A MAY09 BCD	
91.9% MAY19 A			
94.5% A MAY26 AB	107.9% B MAY25 BC	99.1% A MAY25 AB	101.6% AB MAY25 BCD
100.3% JUN01 ABC			

FOOTHILLS WHITE SPRUCE - CONTINUED

<u>4000 FEET</u>	<u>5000 FEET</u>	<u>5800 FEET</u>	<u>6500 FEET</u>
99.5% A JUN08 ABC	100.9% A JUN07 AB	98.6% A JUN06 AB	101.6% A JUN06 CD
105.9% B JUN18 BCD	103.2% AB JUN19 AB	100.1% AB JUN19 AB	97.2% A JUN19 ABC
107.5% B JUN24 BCDE	94.8% A JUN23 A	96.5% A JUN23 AB	90.4% A JUN23 AB
	95.9% A JUL13 A	93.2% A JUL13 A	88.3% A JUL13 A
111.7% C JUL19 CDEFG	101.7% B JUL20 AB	94.4% AB JUL20 A	92.4% A JUL20 ABC
112.4% B JUL27 CDEFG	115.6% B JUL28 CDE	104.0% AB JUL28 ABC	100.2% A JUL28 BC
116.5% A AUG10 DEFGH	132.1% B AUG15 F	119.8% AB AUG15 CDE	113.5% A AUG15 E
125.0% B SEP08 FGHI	128.0% B SEP11 F	125.1% B SEP11 DE	116.8% A SEP11 EF
127.1% A SEP30 HI	136.6% A OCT14 F	130.1% A OCT14 E	128.7% A OCT14 F

TUKEY'S MULTIPLE COMPARISON TEST - SWAN HILLS LODGEPOLE PINE

2400 FEET	3000 FEET	3500 FEET	4200 FEET
136.7% A OCT09 F	123.4% A OCT09 FG	127.6% A OCT09 F	126.0% A OCT09 DEF
134.4% A JAN22 FG	126.9% A JAN22 G	128.2% A JAN22 F	127.5% A JAN22 EF
124.1% AB MAR15 EFG	118.6% A MAR15 EFG	123.5% A MAR15 EF	131.7% B MAR15 F
119.2% AB APR24 DEF	118.2% A APR24 EFG	129.1% B APR24 F	115.0% B APR24 CDE
109.8% A MAY02 ABCDE	111.8% A MAY02 ABCDE	119.2% A MAY02 DEF	112.3% A MAY02 BCDE
101.9% A MAY14 A	98.9% A MAY14 A	102.6% A MAY14 AB	96.8% A MAY14 AB
102.7% A MAY20 AB	96.4% A MAY20 A	99.4% A MAY20 A	96.6% A MAY20 AB
107.5% A MAY31 AB	100.1% A MAY31 AB	105.1% A MAY31 ABC	106.1% A MAY31 BCD
100.0% JUN12 A			94.9% JUN12 A

SWAN HILLS LODGEPOLE PINE - CONTINUED

2400 FEET	3000 FEET	3500 FEET	4200 FEET
105.2% A JUN17 ABC	101.9% A JUN17 AB	105.1% A JUN17 ABC	102.9% A JUN17 ABC
107.8% A JUN22 ABCD	102.0% A JUN22 ABC	100.1% A JUN22 A	102.7% A JUN22 ABC
101.4% A JUL10 A	103.7% A JUL10 ABCD	105.1% A JUL10 ABC	104.2% A JUL10 ABC
118.5% A JUL26 CDE	113.5% A JUL26 DEF	108.6% A JUL26 ABCD	109.2% A JUL26 ABCDE
115.7% A AUG04 BCDE	110.8% A AUG04 BCDE	112.3% A AUG04 BCD	110.8% A AUG04 ABCDE
116.9% A AUG28 CDE	112.9% A AUG28 DE	114.3% A AUG28 CDE	111.8% A AUG28 ABCDE
118.6% B SEP06 CDE	116.0% AB SEP06 EF	110.0% A SEP06 ABCD	110.7% A SEP06 ABCDE
121.2% A OCT15 DEF	115.0% A OCT15 EF	119.4% A OCT15 DEF	117.3% A OCT15 CDEF

TUKEY'S MULTIPLE COMPARISON TEST - SWAN HILLS BLACK SPRUCE

2400 FEET	3000 FEET	3500 FEET	4200 FEET
127.9% B OCT09 CDE	122.2% AB OCT09 F	118.3% A OCT09 D	120.9% A OCT09 DE
128.1% B JAN22 FGH	126.7% B JAN22 GH	117.7% A JAN22 E	125.8% B JAN22 IJ
122.6% B MAR15 FG	117.5% AB MAR15 DEF	114.1% A MAR15 BCD	122.2% B MAR15 E
106.0% A APR24 ABC	103.7% A APR24 ABCD	107.9% A APR24 ABCD	106.0% A APR24 ABCD
106.8% A MAY02 ABC	105.3% A MAY02 BCD	117.2% A MAY02 CD	113.0% A MAY02 BCDE
97.3% AB MAY14 A	93.9% A MAY14 AB	96.8% AB MAY14 A	101.7% B MAY14 AB
99.3% B MAY20 AB	90.2% A MAY20 A	94.3% AB MAY20 A	96.1% A MAY20 A
115.5% B MAY31 C	99.8% A MAY31 ABC	104.5% A MAY31 ABC	104.9% A MAY31 ABC
110.4% JUN09 BC			97,8% JUN12 A

SWAN HILLS BLACK SPRUCE - CONTINUED

2400 FEET	3000 FEET	3500 FEET	4200 FEET
114.3% B JUN17 C	101.6% A JUN17 ABC	100.8% A JUN17 AB	107.8% AB JUN17 ABCD
119.2% B JUN22 CD	108.9% A JUN22 DE	111.4% AB JUN22 BCD	114.8% AB JUN22. BCDE
118.2% A JUL10 CD	107.5% A JUL10 DE	110.4% A JUL10 BCD	111.8% A JUL10 BCDE
132.7% B JUL26 DE	120.0% AB JUL26 EF	113.9% A JUL26 BCD	123.6% AB JUL26 E
120.2% A AUG04 CDE	115.1% A AUG04 DEF	113.5% A AUG04 CD	120.3% A AUG04 DE
119.8% A AUG28 CDE	115.1% A AUG28 DEE	116.3% A AUG28 CD	118.0% A AUG28 CDE
130.4% B SEP06 CDE	117.8% A SEP06 DEF	114.8% A SEP06 CD	116.1% A SEP06 CDE
126.2% A OCT15 CDE	125.1% A OCT15 F	120.4% AB OCT15 D	126.2% A OCT15 E

TUKEY'S MULT. RGE TEST - LODGEPOLE PINE ON FOUR ASPECTS

Date	NORTH			EAST			SOUTH			WEST		
NOV12	132.8%	A	GH	130.0%	A	G	128.2%	A	E	131.3%	A	F
FEB12	130.4%	A	FGH	132.2%	A	G	127.7%	A	E	131.4%	A	F
APR11	131.5%	A	FGH	128.7%	A	FG	126.2%	A	E	130.5%	A	EF
APR25	125.7%	A	EFGH	124.2%	A	EFG	117.5%	A	DE	126.6%	A	EF
MAY03	114.2%	A	CD	115.3%	A	ABCDE	108.1%	A	ABC	108.6%	A	ABC
MAY10	110.6%	A	BC	113.8%	A	ABCDE	106.6%	A	ABC	111.3%	A	ABC
MAY19	104.1%	AB	AB	108.0%	B	ABC	100.3%	A	A	102.6%	AB	A
MAY26	100.0%	AB	A	104.6%	B	AB	96.7%	A	A	99.7%	AB	A
JUN01	106.8%	A	ABC	113.9%	A	BCDE	102.6%	A	AB	104.4%	A	AB

LODGEPOLE PINE ON FOUR ASPECTS - CONTINUED

NORTH	EAST	SOUTH	WEST
105.4% A JUN08 AB	105.7% A JUN08 ABC	99.9% A JUN08 A	102.2% A JUN08 A
106.3% AB JUN18 ABC	110.9% B JUN18 ABCDE	101.7% A JUN18 AB	105.0% AB JUN18 AB
105.0% A JUN24 AB	109.5% A JUN24 ABCD	100.1% A JUN24 A	106.6% A JUN24 ABC
103.0% A JUL04 AB	99.2% A JUL04 A	98.9% A JUL04 A	104.6% A JUL04 AB
114.1% A JUL19 CD	111.5% A JUL19 ABCDE	106.2% A JUL19 ABC	110.5% A JUL19 ABC
121.4% A JUL27 EF	119.1% A JUL27 CDEFG	114.5% A JUL27 DE	116.1% A JUL27 E
123.6% A AUG10 EF	119.4% A AUG10 CDEFG	117.2% A AUG10 DE	118.4% A AUG10 CD
133.2% A SEP08 H	128.3% A SEP08 FG	125.3% A SEP08 E	125.9% A SEP08 DEF
124.9% A OCT16 EFG	123.4% A OCT16 DEFG	122.4% A OCT16 E	117.9% A OCT16 CD

APPENDIX 4 - SOIL TEMPERATURES

Figures 32 through 34 display isoquants of the soil temperatures measured on the elevational sampling locations from the end of March, 1977 to July, 1977. There are two graphs for each area, showing the temperatures measured at both 15 and 30 cm depths, respectively. Figure 33 contains composite isoquants for both areas for the entire elevational gradient combined.

Figure 32. Isoquants of soil temperature on elevation by date for 15 cm (right) and 30 cm (left) depths for foothills sample locations

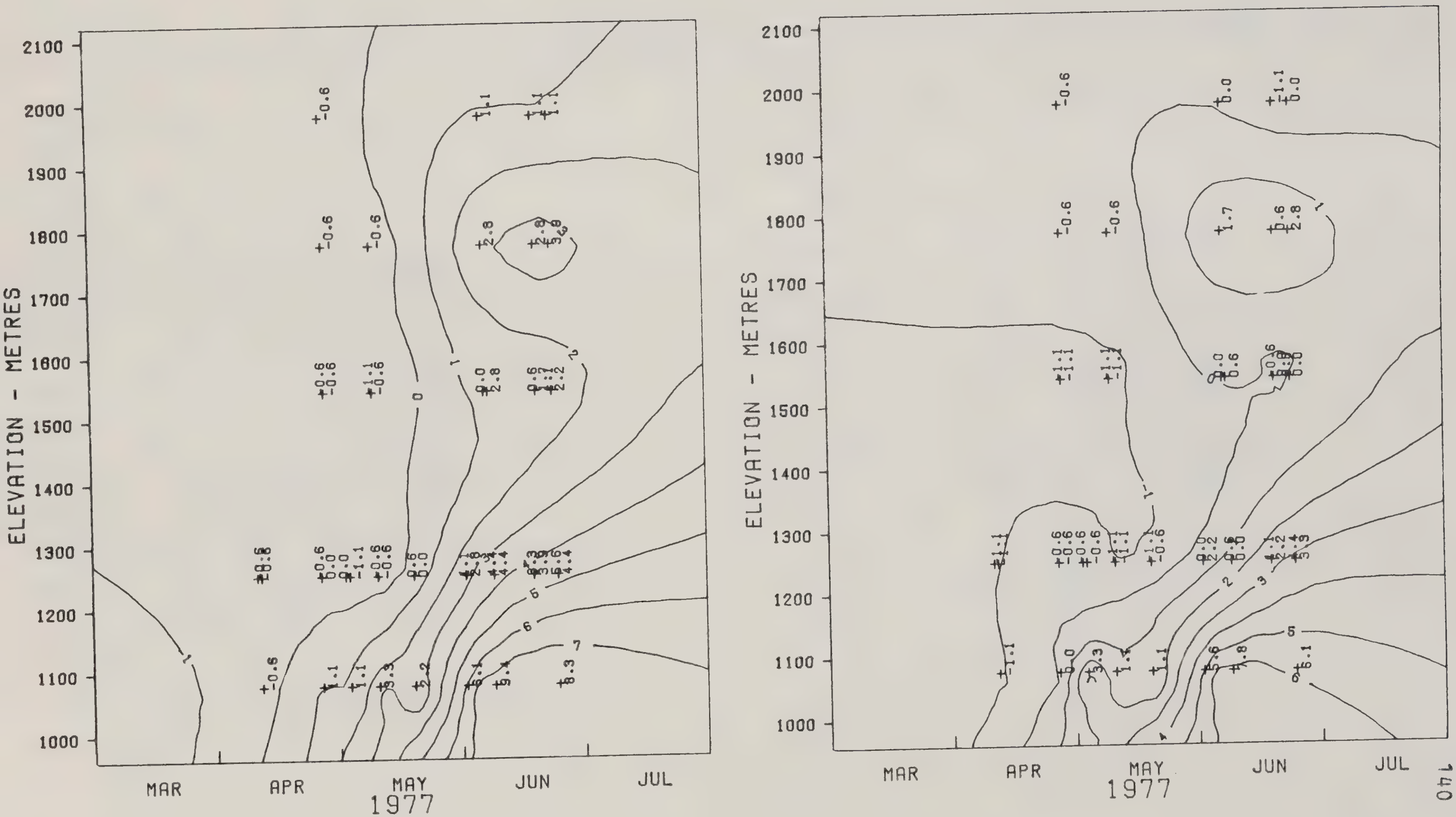


Figure 33. Isoquants of soil temperature on elevation by date for 15 cm (right) and 30 cm (left) depths for Swan Hills sample locations

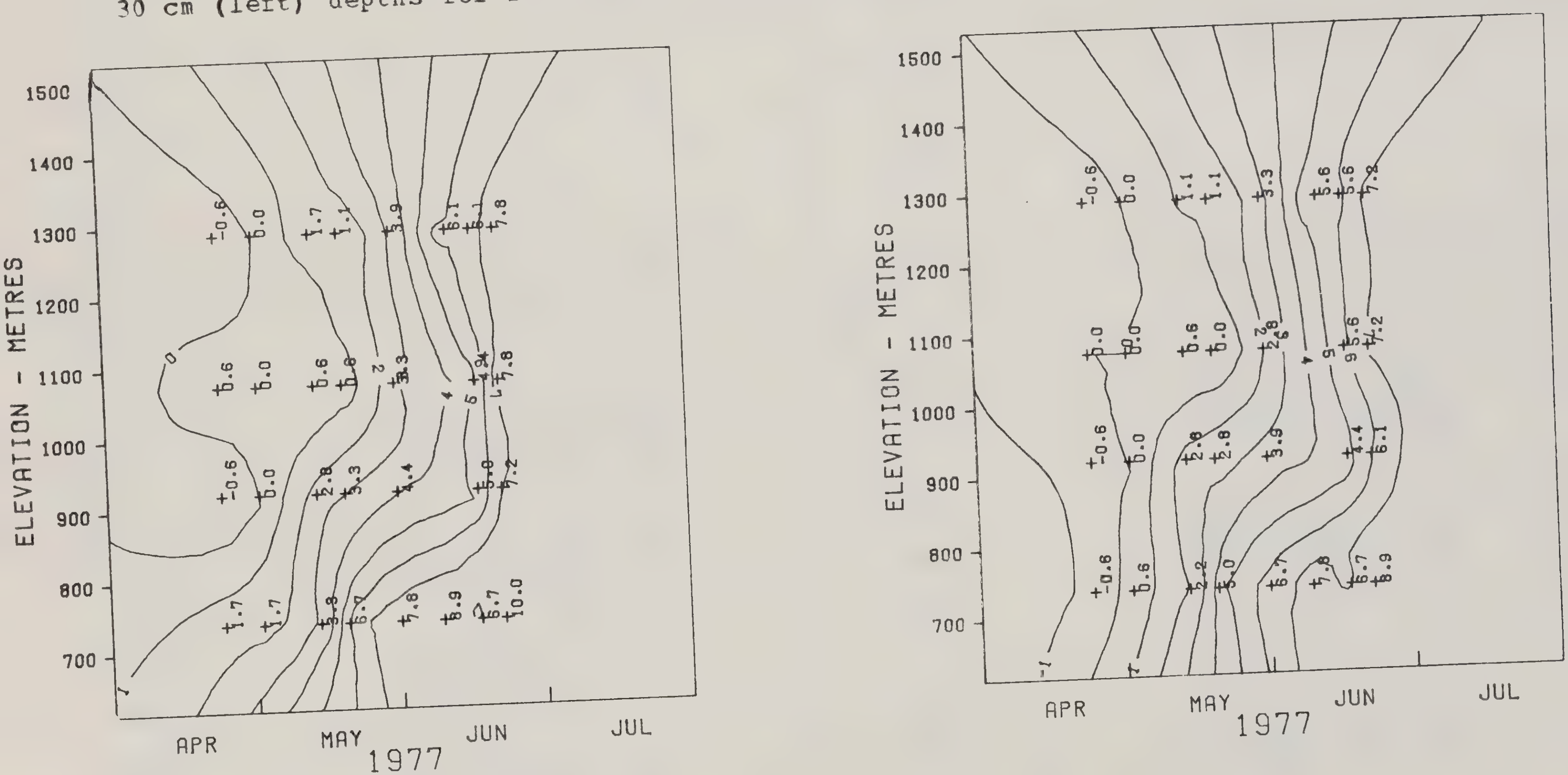
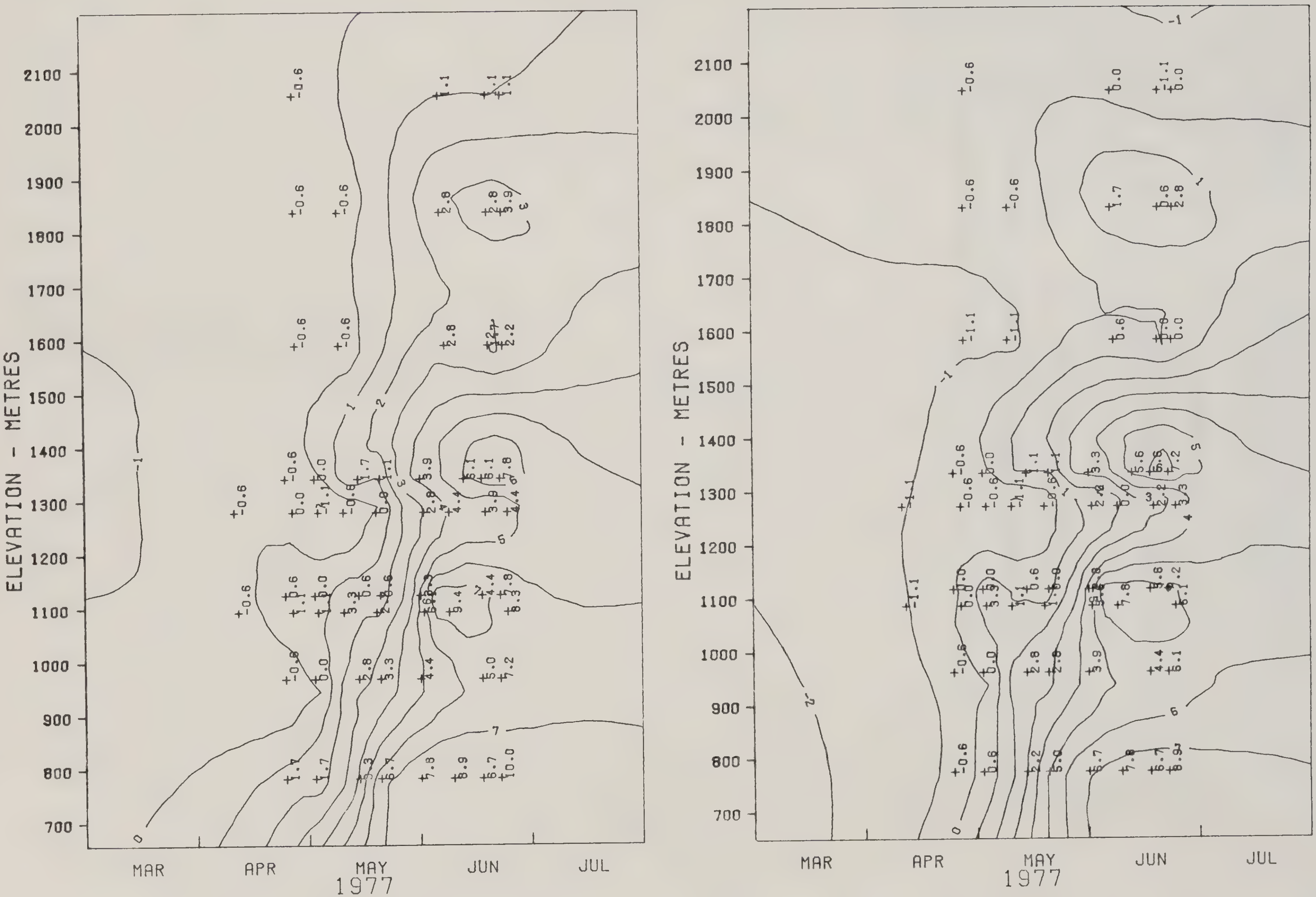


Figure 34. Isoquants of soil temperature on elevation by date for 15 cm (right) and 30 cm (left) depths for both foothills and Swan Hills sample locations



APPENDIX 5 - PHYSIOLOGICAL DEVELOPMENT

Figures 35 through 39 represent smoothed lines through the points of observed linear growth of the 1977 foliage as estimated from the sampled branches at each sampling location. As well, the estimated dates of flushing are presented, the male strobili bursting dates are indicated with a solid arrow and needle bud burst indicated with a clear arrow.

Figure 35. Estimated flushing dates (50% bud-burst for sampled branches) of reproductive and vegetative buds with linear growth for 1977 foliage of lodgepole pine on foothills sampling locations.

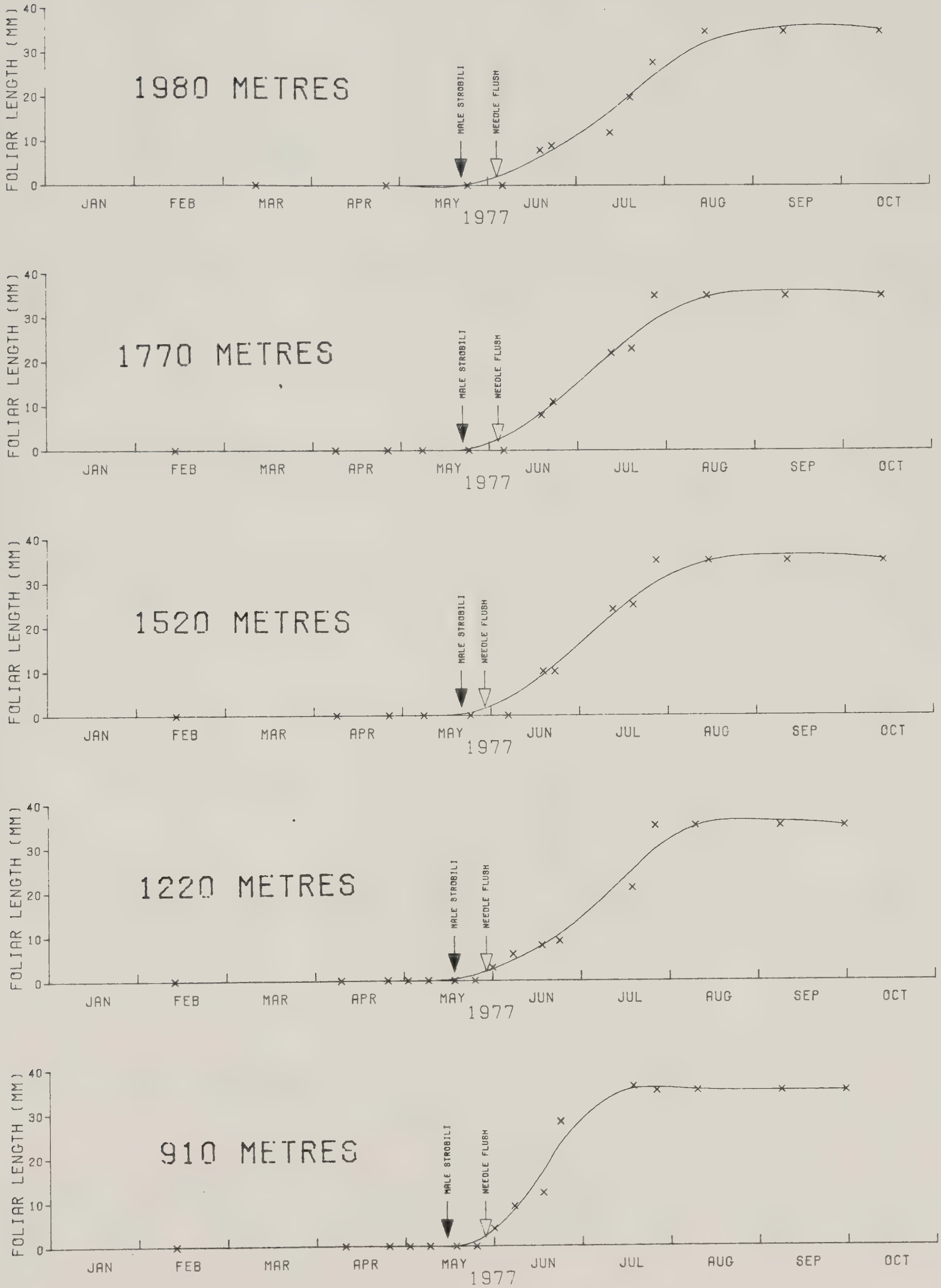
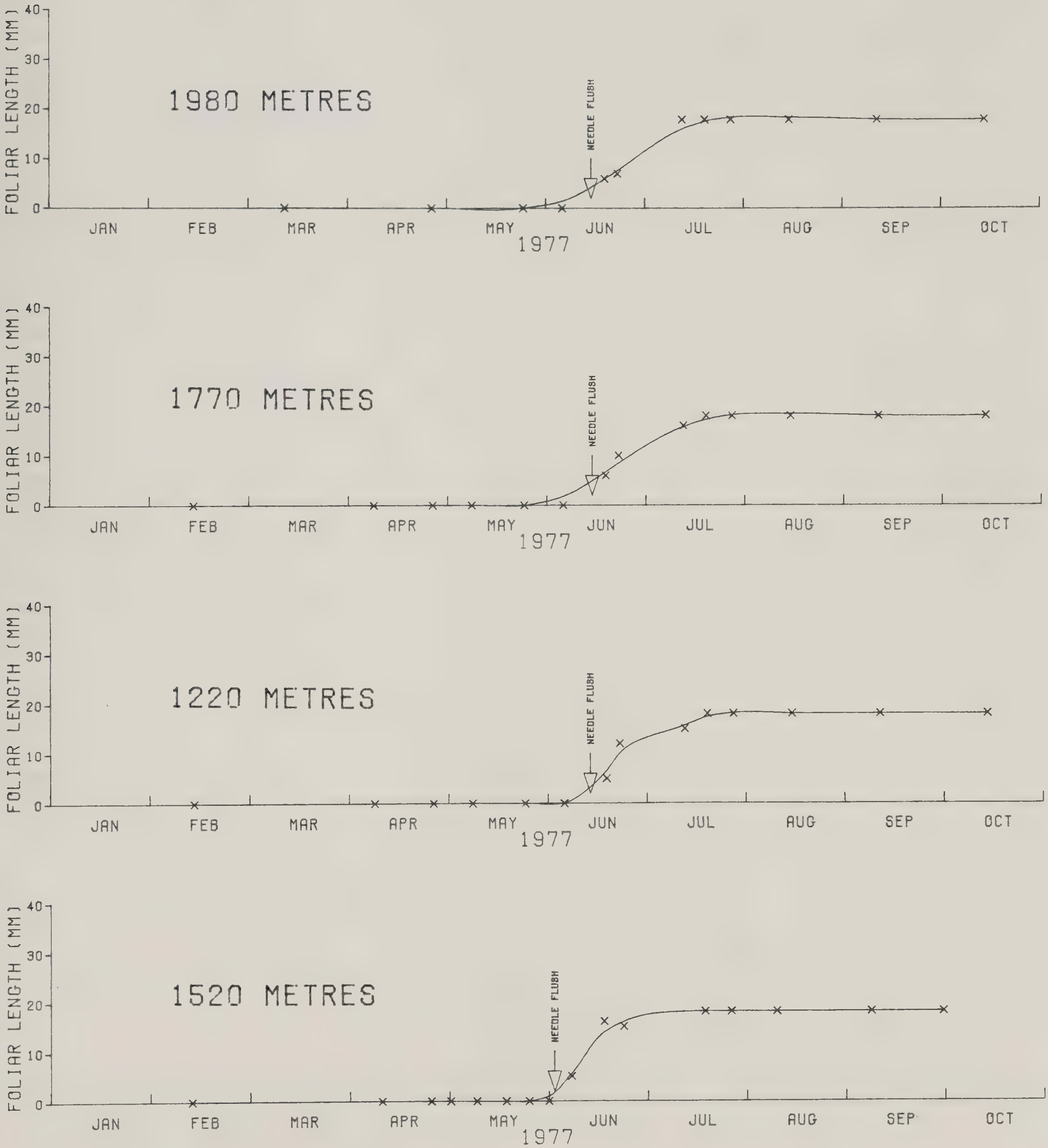


Figure 36. Estimated flushing dates (50% bud-burst for sampled branches) of vegetative buds (reproductive buds not apparent) with linear growth for 1977 foliage for white-Engelmann spruce on foothills sampling locations.



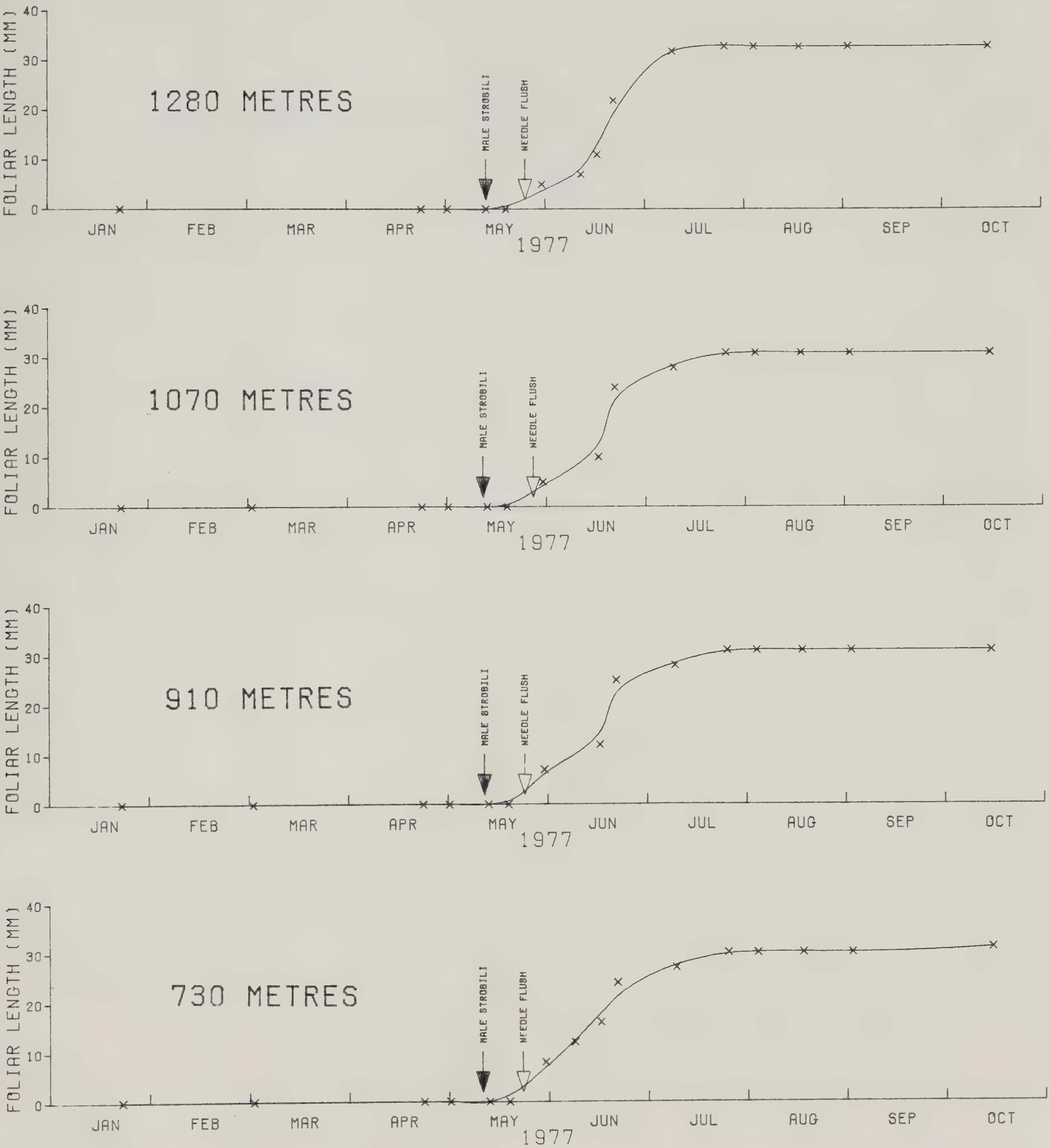


Figure 37. Estimated flushing dates (50% bud-burst for sampled branches) of reproductive and vegetative buds with linear growth for 1977 foliage of lodgepole pine on Swan Hills sampling locations.

Figure 38. Estimated flushing dates (50% bud-burst for sampled branches) of reproductive and vegetative buds with linear growth for 1977 foliage of black spruce on Swan Hills sampling locations.

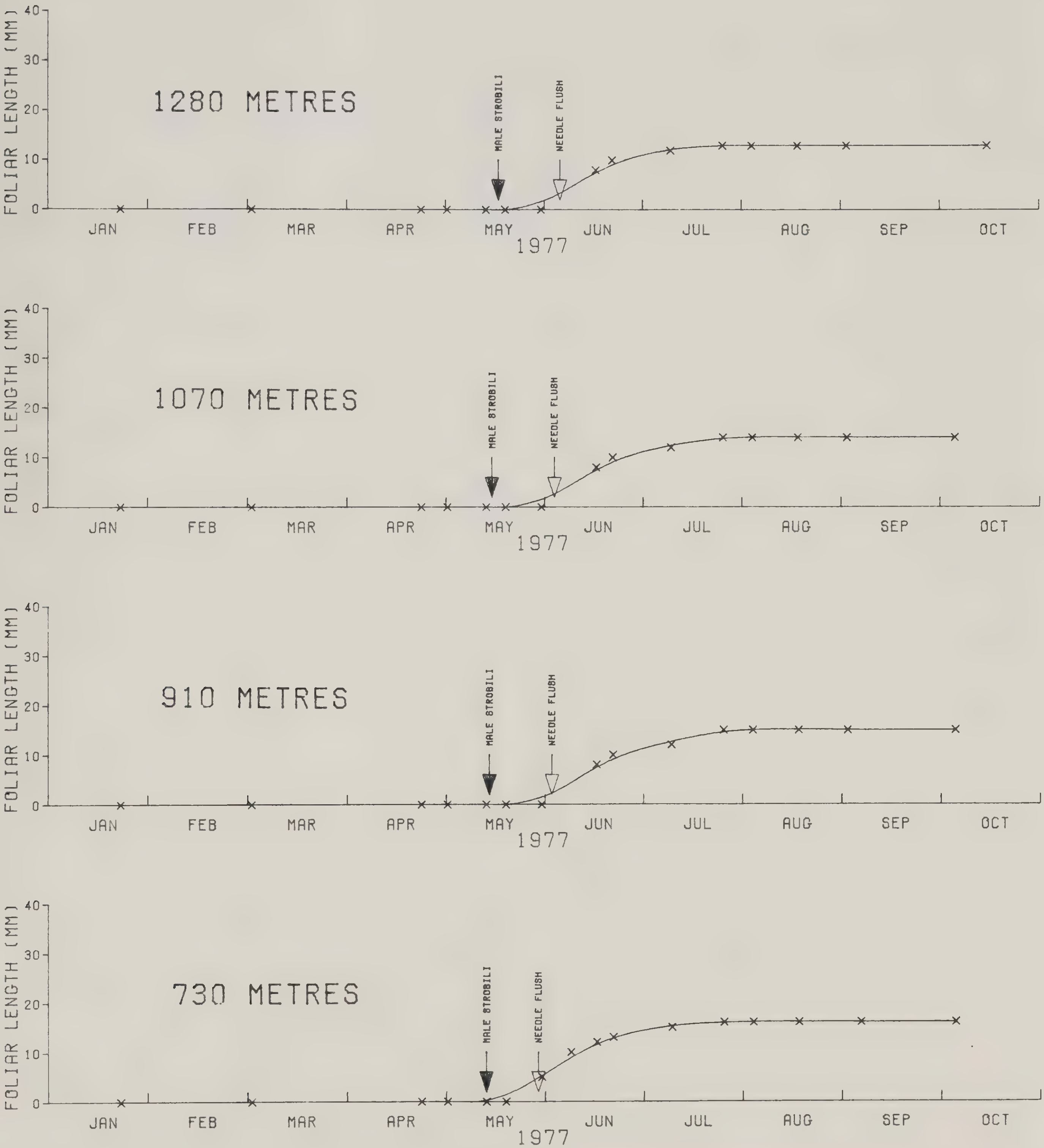


Figure 39. Estimated flushing dates (50% bud-burst for sampled branches) of reproductive and vegetative buds with linear growth for 1977 foliage of lodgepole pine on four aspects at a sampling location in the foothills.